CHAPTER X. PRIORITY HABITAT ISSUES: HABITAT MONITORING TO ASSESS STATUS, TRENDS, AND REGULATORY EFFECTIVENESS

1.1. Issue

An understanding of the status and trends of NC's six coastal habitats, and the ability to monitor them over time, is needed to assess both the long term changes to the habitats and the causative effects. Comprehensive mapping and monitoring, of all of NC's coastal habitats, is needed to quantifiably measure the necessity and success of management actions and restoration efforts. Adequate spatial coverage and resolution can inform protection and restoration efforts and can provide indicators of larger changes in the system that may need to be investigated in the future (Thayer et al. 2005). Various levels of mapping and monitoring of the six coastal habitats occurs in NC. However, more unified, robust, and standardized approaches would increase the ability to report on the health of NC's coastal ecosystem including detecting change and potential causation. This approach will better inform protection and restoration efforts and support current or potential management actions. The need for rapid habitat assessment to facilitate habitat restoration and protection have been recognized by the CHPP since its inception (Street et al. 2005). Building from this, generating metrics for assessing habitat trends was a priority issue in the2016 Coastal Habitat Protection Plan (CHPP; NCDEQ 2016). While some progress was made, the purpose of this paper is to advance standardized and regular monitoring of NC's coastal habitats.

1.2. Origination

The CHPP Team and Steering Committee

1.3. Background

The Fisheries Reform Act of 1997 (G.S. 143B-279.8) specifies that the CHPP identify threats and recommend management actions to protect and restore habitats critical to North Carolina's coastal fishery resources. The legislative goal of the CHPP is ***"…the long-term enhancement of coastal fisheries associated with coastal habitats."*** The statute specifies the plan must include evaluation of the status and trends of fish habitat. A species' use of specific areas can depend on various factors, including life stage, time of day, and tidal stage. Together, these habitat areas form a functional and connected system that supports the fish from spawning until death. Because of the interconnectedness and functions that each habitat provides, the status of one habitat can affect others. Within NC's coastal ecosystem, six habitat types were distinguished: water column, shell bottom, submerged aquatic vegetation (SAV), wetlands, soft bottom, and hard bottom.

Recognizing the problems caused by degradation and destruction of the environment and identifying the causes, both natural and human induced, is essential in raising public awareness. Yet, this is only the starting point for environmental management (O'Higgins et al. 2020). Coastal resource managers have to consider the complex interactions between and within the coastal habitats, the estuarine ecosystems as a whole, and the human population creating the need for standardized monitoring and assessments of these habitats. The primary purpose of monitoring is to collect information that can be used for development of policy, examine the outcomes of management actions, and guide management decisions (Kull et al. 2008). Habitat monitoring at local to regional scales is essential given their vulnerability to human pressures and those associated with climatic fluctuation (Nagendra et al. 2012).

To quantifiably achieve the main goal of the CHPP, the status and trends of these six coastal habitat types must be monitored over time to assess long-term changes. This information can then be used, not only to educate the public on the condition of the coastal habitats, but also to inform protection and restoration decisions and evaluate and adapt management actions and strategies (Figure X.1).

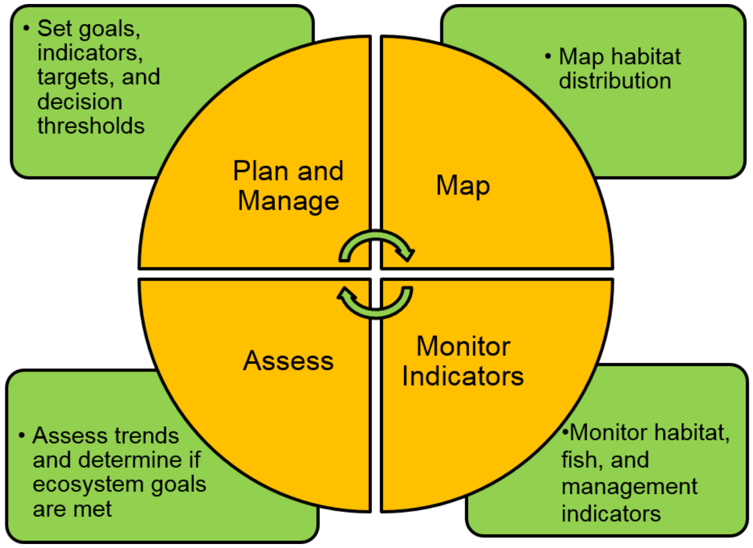

Figure X.1. The role of monitoring in successful habitat management (adapted from APNEP 2012a).

The integration of social and ecological information relevant to stakeholders and managers is an essential component when trying to reach management goals and remediate environmental impacts (Elliot and O'Higgins 2020). The 2016 CHPP recognized this and the need to incorporate ecosystem-based management (EBM) into coastal resource conservation strategies (NCDEQ 2016). The following management options were proposed:

1. Develop indicator metrics for monitoring the status and trends of each of the six habitat types within North Carolina's coastal ecosystem (water column, shell bottom, SAV, wetlands, soft bottom, hard bottom).
2. Establish thresholds of habitat quality, quantity, or extent, similar to limit reference points or traffic lights, which would initiate pre-determined management actions.
3. Develop indicators for assessing fish utilization of strategic coastal habitats.
4. Develop performance criteria for measuring success of management decisions.
5. Include specific performance criteria in CHPP management actions where possible.

Ecosystem based management is a shift away from a limited or partial consideration of the interactions of the natural systems and society. The emphasis of EBM is: 1) factoring in complex linkages in social-ecological systems; 2) dealing with adequate scales (both spatially and temporally); 3) promoting adaptive management of complex and dynamic systems; and 4) adopting integrated assessment and management frameworks (Delacámara et al. 2020). While the concept of EBM has been widely accepted and research into social-ecological systems has provided a very promising direction for improved environmental management, to date there has been limited progress in incorporating such practice into large scale policy (O'Higgins et al. 2020). This is evident in the implementation of the above proposed management options. Although notable implementation progress has been made in developing indicators for assessing fish use of strategic habitat areas (See Chapter 2. Implementation Progress on Priority Habitat Issues for additional information), substantial work is still needed on the proposed management options to develop indicator metrics and performance criteria. Therefore, a first step in understanding ecosystem level trends is to assess individual habitat status and trends.

While there are permanently funded programs for monitoring fish and water quality, programs for continuous monitoring and assessment of the coastal habitats are very limited or absent due to lack of funding for long-term data collection not directly related to agency mission statements and regulatory compliance. The description, distribution, ecological role, and functions of the six coastal habitats can be found in the 2016 CHPP source document. The following details the most up to date status and trends for each of the six coastal habitats using the most current and available monitoring data. For additional information on SAV and wetlands, please refer to the Protection and Restoration of Submerged Aquatic Vegetation with Focus on Water Quality and Wetland Shoreline Protection and Enhancement with Focus on Nature-Based Methods issue papers.

1.4. Status and Trends of North Carolina’s Coastal Habitats

1.4.1. Water Column

The water column habitat is defined as “water covering a submerged surface and its physical, chemical, and biological characteristics” (Street et al. 2005). The chemical and physical properties of the water affect the biological components of the water column - including fish distribution. The water column is the medium through which all aquatic habitats are connected and is therefore critical to the overall health of the ecosystem.

Water quality describes the condition of waters based on selected physical, chemical, and biological characteristics, usually with respect to its suitability for a particular purpose such as drinking, recreation, or supporting aquatic life. Fish species and other organisms, such as SAV and oyster that also provide fish habitat, exhibit threshold tolerances. Conditions of the water column that are outside the threshold tolerance are considered impaired, polluted, or otherwise not supporting aquatic life. Basic parameters of water impairment include: pH, temperature, DO, turbidity, bacteria, and nutrient indicators such as nitrogen, phosphorus, and chlorophyll *a*. Excessive nutrient-rich sediment from land-based activities can exacerbate eutrophication, decreasing DO and water clarity and increasing toxic contamination. Therefore, flow and movement play a vital role in distributing the drivers of eutrophication and chemical pollution.

2010 National Coastal Condition Assessment (NCCA)

A national assessment, the United States Environmental Protection Agency (USEPA) 2010 National Coastal Condition Assessment (NCCA) found in the Southeast Coastal region (North Carolina to Florida), 21% of the coastal area is in good condition based on the water quality index, 69% is in fair condition, and 9% is in poor condition (Figure X.2; USEPA 2015). Ratings for chlorophyll *a* and phosphorus contribute most to the region’s fair and poor water quality scores. Between the 1999–2001 and the 2005–2006 reporting periods, the Southeast coastal region that was rated good based on the water quality index declined significantly by 27% (Figure X.3). Dissolved oxygen and water clarity seem to be primary drivers for this decrease in quality. Between the 2005–2006 and the 2010 reporting periods, there was a modest increase in the percent area rated good based on the water quality index. A significant rise in the percent area rated good for dissolved oxygen and water clarity conditions and a small but significant change in nitrogen conditions contributed to the improvement in 2010.

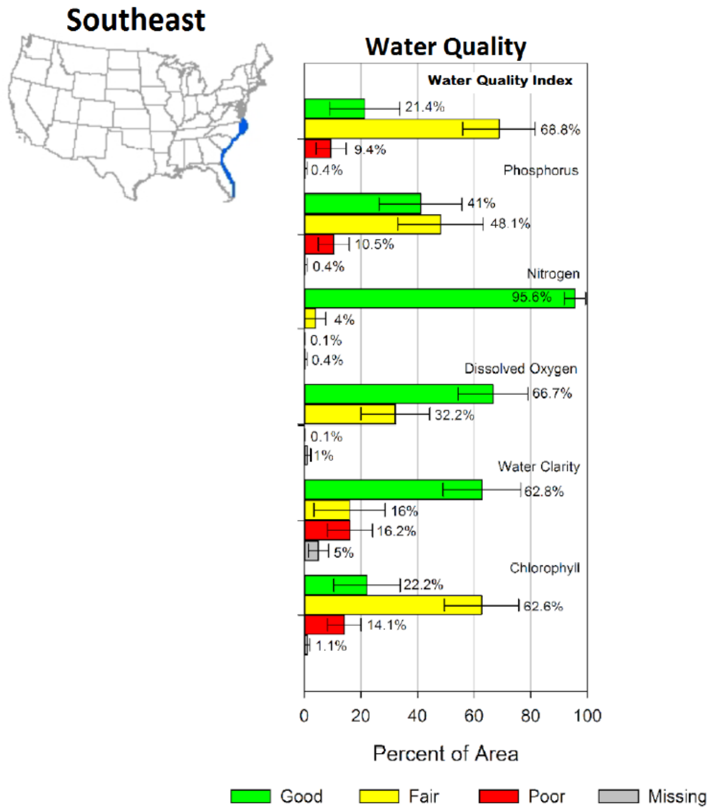

Figure X.2. The USEPA National Coastal Condition Assessment (NCCA) 2010 water quality index results for the Southeast Coastal region. Bars show the percent of coastal area within a condition category for specific indicators. Error bars represent 95% confidence intervals. Note: The sum of percent of area for each indicator may not add up to 100% due to rounding. (Source: USEPA 2015)

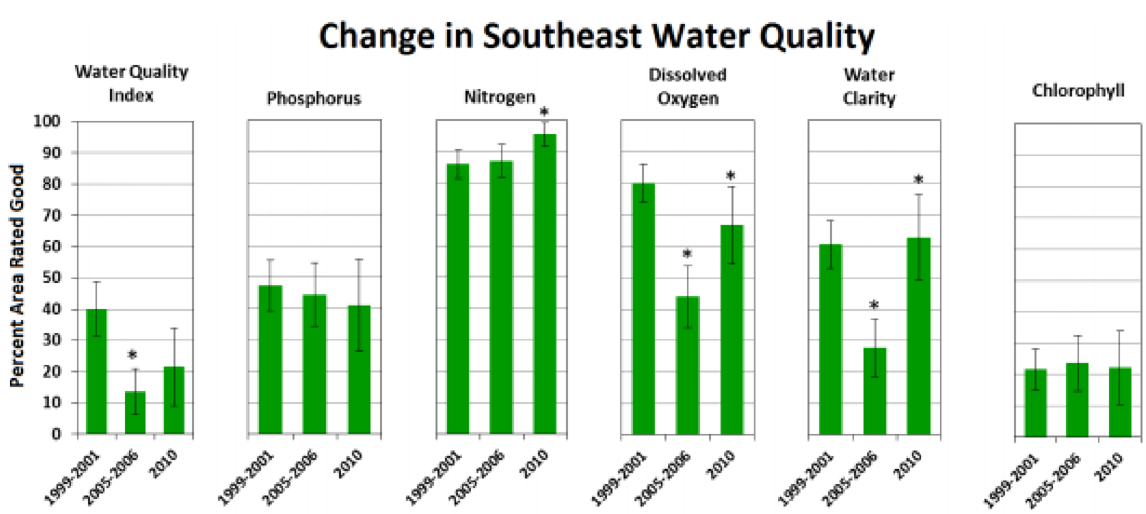

Figure X.3. Comparison of the percent area rated good for water quality indicators over three periods in the Southeast Coast. Note: Asterisks (*) indicates statistically significant change between periods. (Source: USEPA 2015).

North Carolina Division of Water Resources (DWR) Ambient Monitoring System (AMS)

The DWR is the primary water quality monitoring agency in NC. Surface waters in NC are assigned a classification reflecting the uses of that waterbody (e.g., water supply, shellfish harvest, primary recreation, aquatic life, agriculture). To determine how well waterbodies are meeting their best-intended uses, chemical, physical, and biological parameters are regularly assessed by DWR. The assessment of water quality in NC, known as the Integrated Report (IR) is required under Sections 303(d) and 305(b) of the Clean Water Act and is completed biennially. This assessment indicates the general condition of NC's waters and identifies waters that are not meeting water quality standards where sufficient data exists.

The impaired waters (acres and miles) listed in the 2018 IR are shown in Table X.1 by region and for the overall coast. Additional information about the Integrated Report can be found here: https://deq.nc.gov/about/divisions/water-resources/planning/modeling-assessment/water-quality-data-assessment/integrated-report-files.

Table X.1. The impaired waters (acres and miles) listed in the 2018 Integrated Report. Percent of waters assessed in parentheses.

	2018 Integrated Report Impaired Waters				
	Region 1	Region 2	Region 3	Region 4	Overall
Freshwater (ac)	15,600 (42%)	0.0 (0.0%)	0.0 (0.0%)	289 (67%)	15,889 (34%)
Freshwater (mi)	43 (5%)	304 (18%)	12.4 (14%)	123 (9%)	482 (12%)
Saltwater (ac)	349,699 (43%)	204,534 (15%)	47,597 (6%)	16,470 (42%)	618,300 (20%)
Atlantic Coast (mi)	0.0 (0.0%)	0.0 (0.0%)	0.6 (0.4%)	0.0 (0.0%)	0.6 (0.2%)

Several of DWR's water quality management activities use data produced by the Ambient Monitoring System (AMS). The AMS consists of a network of stations established to provide site-specific, long-term water quality information on significant waterbodies throughout the state (Figure X.4). The program has been active for over forty years and is used in development of the IR, Basinwide Water Resources Plans, Total Maximum Daily Loads (TMDLs), and National Pollutant Discharge Elimination System (NPDES) permit limits. Active stations are visited at least quarterly for the collection of a variety of physical, chemical, and bacterial pathogen samples and measurements. Stations monitoring water quality are concentrated in riverine and upper estuarine waters. Currently there are 329 active stations, 149 of which are within the coastal boundaries of the CHPP regions. Water quality data (e.g., chlorophyll *a*, nutrients, pH, DO, and turbidity) from a representative 18 DWR AMS stations throughout the CHPP regions are shown in Figure X.4 and summarized graphically by year in Figures X.5-X.8. The graphs are not statistical trends or meant to show standard exceedance, but are generated to show general trends over the years. These sites were also summarized in the 2016 CHPP (NCDEQ 2016).

Ambient Monitoring System (AMS) Coastal Habitat Protection Plan (CHPP) Region 1

The five selected stations in CHPP Region 1 include:

- Roanoke River near Williamston (N8550000),
- Chowan River near Colerain (D8950000),
- Albemarle Sound near Edenton (D999500C),
- Albemarle Sound near Frog Island (M390000C), and
- Pasquotank River near Elizabeth City (M2750000; Figure X.4).

Annual mean water quality data indicate:

- Total phosphorus (TP) levels are higher in the rivers versus Albemarle Sound;

- Total nitrogen (TN) is increasing in all the stations, the Pasquotank River showed higher concentrations especially during the wetter years;
- Turbidity data shows peaks during wetter years and higher concentrations in the Roanoke River;
- High and low DO levels may indicate the growth and crash of algal production within these waterbodies. The low DO in the Roanoke and Pasquotank are due to excess swamp drainage during wet years;
- Median pH levels fluctuate at each station with the levels not indicating any extended periods of standard exceedance. The Roanoke and Pasquotank are influenced by swamp water draining into these systems which can result in naturally low DO and pH levels;
- Chlorophyll *a* concentrations indicate that the mean concentration is increasing throughout this region. A dramatic increase has been identified in the Chowan River at the Colerain station (D8950000) where summer nuisance algal blooms have been documented since about 2015 (Figure X.5)

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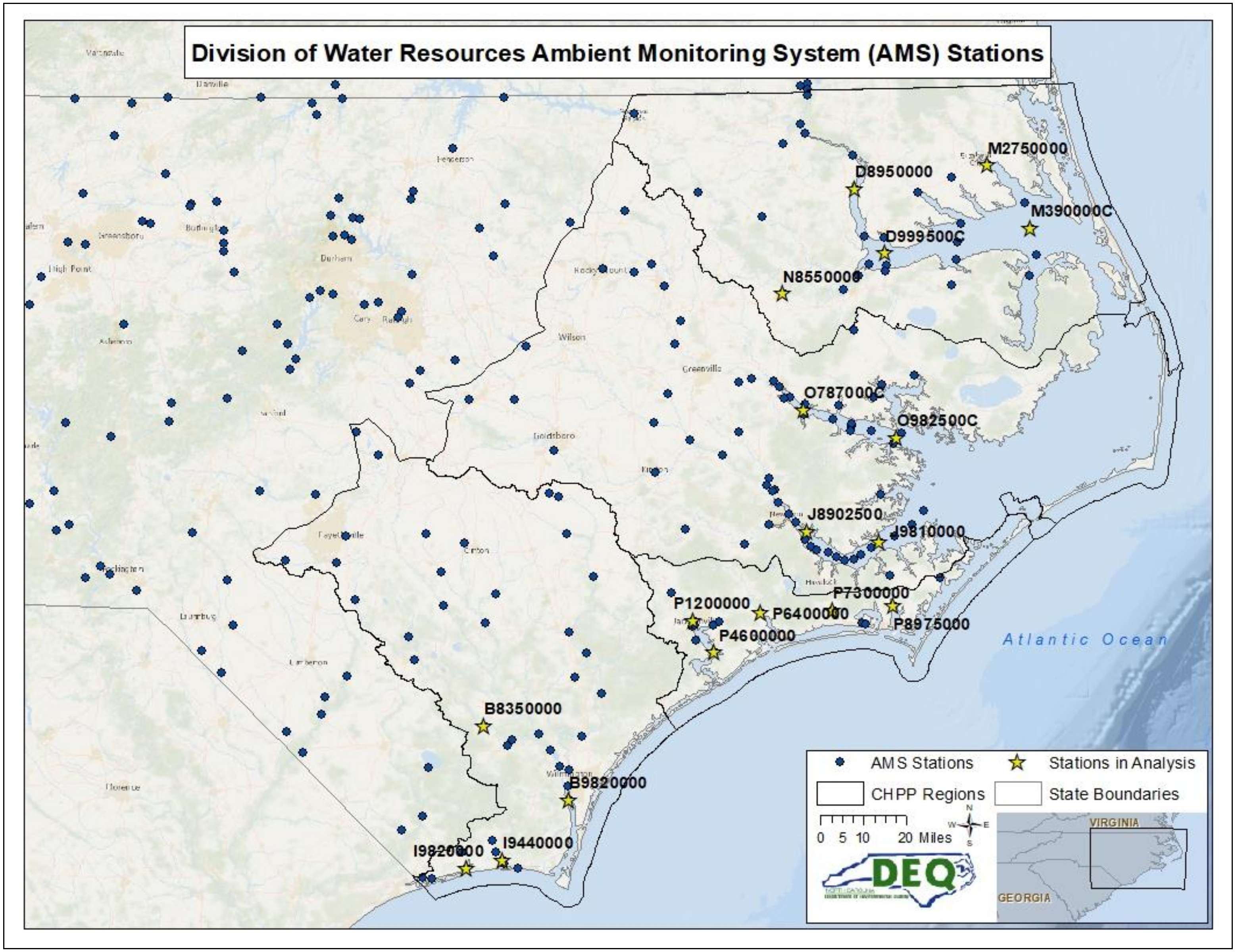

Figure X.4. The Division of Water Resources (DWR) Ambient Monitoring System (AMS) Stations.

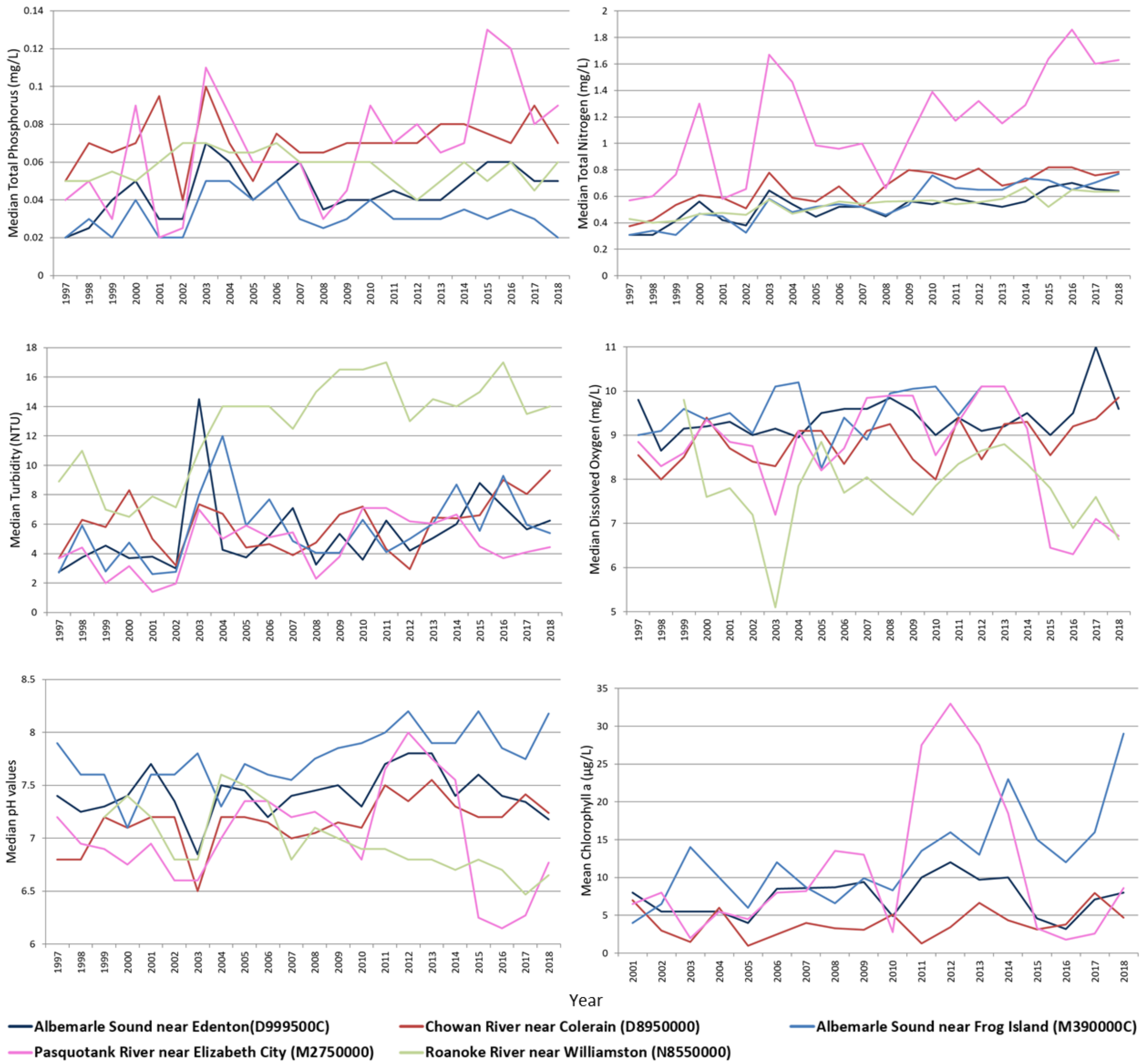

Figure X.5. Annual median Total Phosphorus (mg/L), total Nitrogen (mg/L), Turbidity (NTU), DO (mg/L) concentrations, and pH values, and mean Chlorophyll a (µg/L) concentrations for five representative Ambient Monitoring System (AMS) stations in Coastal Habitat Protection Plan (CHPP) Region 1.

Ambient Monitoring System (AMS) Coastal Habitat Protection Plan (CHPP) Region 1

The four selected stations in CHPP Region 2 include:

- Pamlico River mid-channel at the mouth of Brad Creek near Bunyon (O787000C),
- Pamlico River mid-channel between the mouths of the Pungo River and Goose Creek (O982500C),
- Neuse River near Thurman (J8902500), and
- Neuse River near Oriental (J9810000; Figure X.4).

Annual mean water quality data indicate:

- Data from the two upper and lower estuary stations show similar patterns over the years.

- The graphs clearly show higher nutrient levels in the upper estuary, whereas dilution and biological uptake has occurred resulting in lower concentrations of TP and TN at the lower estuarine stations.
- The median TN concentrations are clearly increasing over the 21-year period.
- Chlorophyll *a* concentration has remained fairly consistent over this time period with elevated concentrations at the upstream station and a significant spike in the 2014 annual mean concentration of 117 µg/L at the Neuse River J8902500 station. A prolonged period of elevated biological productivity occurred between July and December 2014. The chlorophyll *a* concentration ranged between 55-780 µg/L, with a mean concentration of 206 µg/L (Figure X.6).

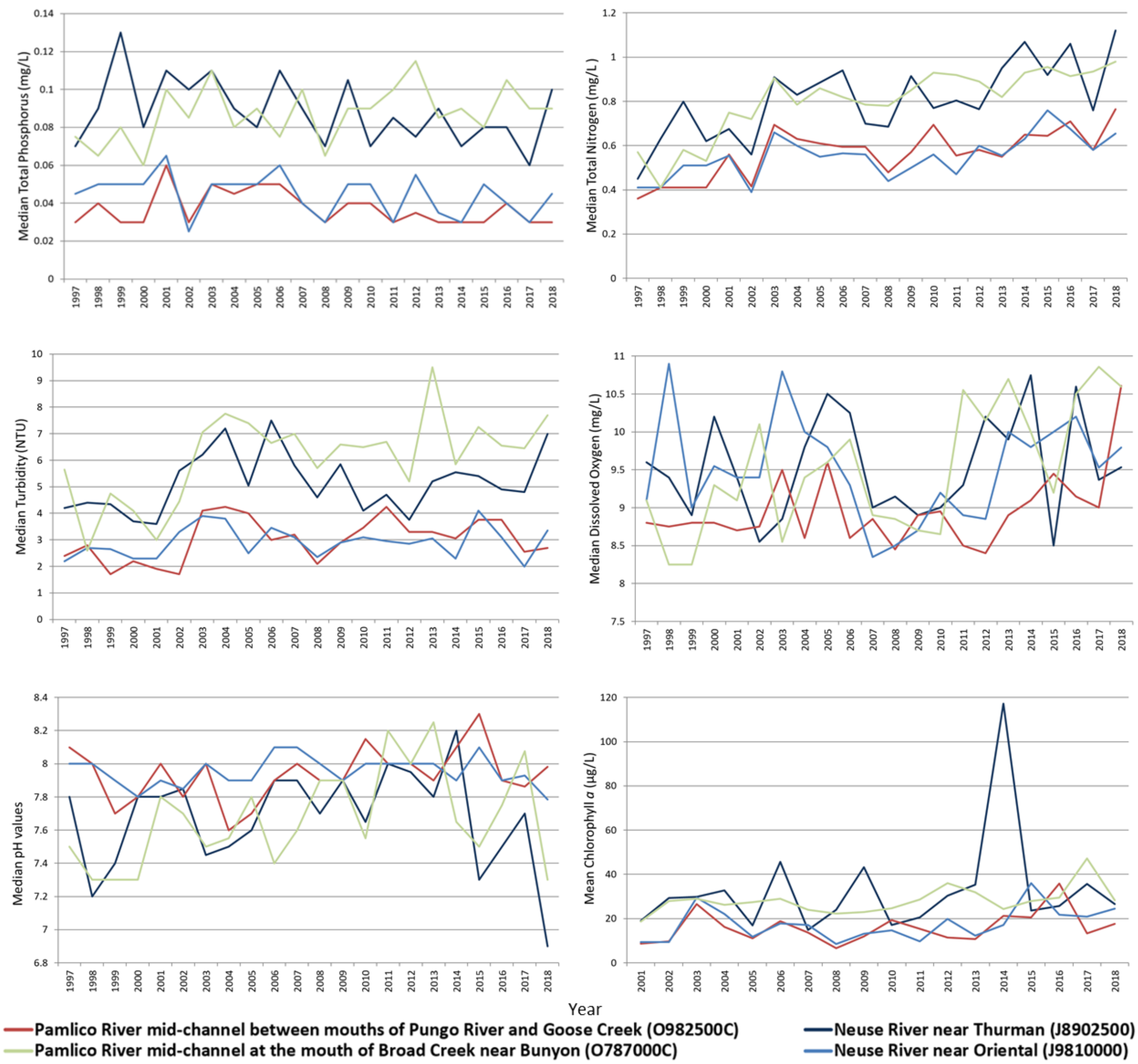

Figure X.6. Annual median Total Phosphorus (mg/L), total Nitrogen (mg/L), Turbidity (NTU), DO (mg/L) concentrations, and pH values, and mean Chlorophyll a (µg/L) concentrations for five representative Ambient Monitoring System (AMS) stations in Coastal Habitat Protection Plan (CHPP) Region 2.

Ambient Monitoring System (AMS) Coastal Habitat Protection Plan (CHPP) Region 3

The five selected stations in CHPP Region 3 include:

- North River near Bettie (P8975000),
- Newport River near Newport (P7300000),
- White Oak River near Stella (P6400000),
- New River near Jacksonville (P1200000), and
- New River upstream of French Creek (P4600000) (Figure X.4).

Annual mean water quality data indicate:

- Nutrient data was only collected at the New River stations; this data shows much higher concentrations near Jacksonville than downstream in the New River estuary.
- This is generally reflected in the chlorophyll a biological response with higher mean concentrations at the New River near Jacksonville station (P1200000). Higher concentrations can occur downstream when flows are high enough to limit the productivity upstream due to stream flows limiting for algal bloom development.
- Turbidity data shows much higher concentrations in the North River near Bettie station (P8975000) than in other coastal rivers.
- DO and pH levels are much lower at the Newport River near Newport station (P7300000) than other coastal stations (Figure X.7).

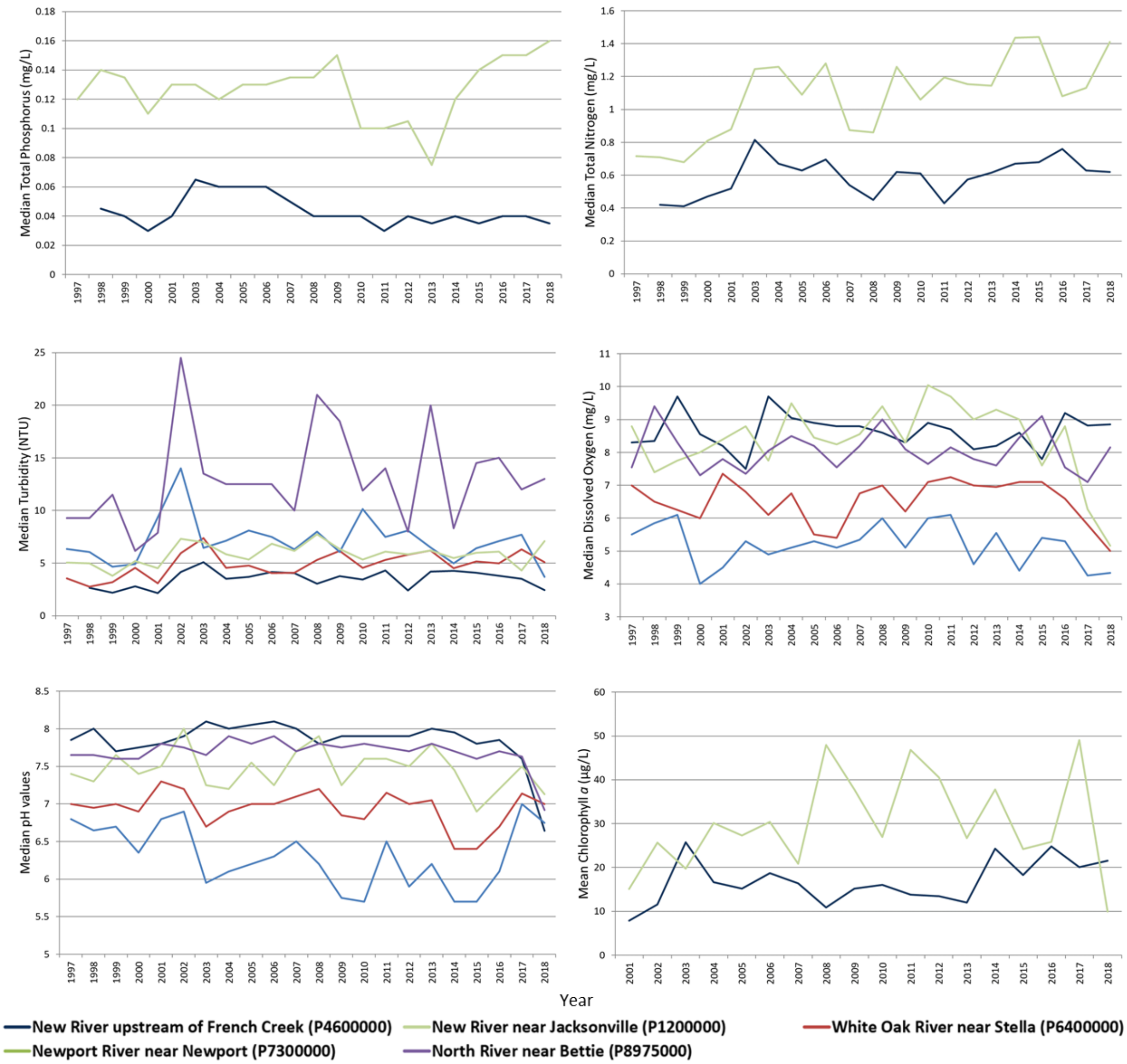

Figure X.7. Annual median Total Phosphorus (mg/L), total Nitrogen (mg/L), Turbidity (NTU), DO (mg/L) concentrations, and pH values, and mean Chlorophyll a (µg/L) concentrations for five representative Ambient Monitoring System (AMS) stations in Coastal Habitat Protection Plan (CHPP) Region 3.

Ambient Monitoring System (AMS) Coastal Habitat Protection Plan (CHPP) Region 4

The four selected stations in region 4 include:

- Cape Fear River near Kelly (B8350000, below lock and dam #1),
- Cape Fear River near Wilmington (B9820000),
- Lockwood Folly near Varnum (I9440000), and
- Shallotte River near Shallotte (I9820000) (Figure X.4).

Annual mean water quality data indicate:

- Nutrient data was only collected at the Cape Fear River stations with the higher concentration data indicated in the upstream station.

- The upstream Cape Fear River station (B8350000) also shows a larger range of turbidity concentrations.
- Lower pH conditions in the Cape Fear River stations are likely the result of swamp drainage influence (Figure X.8).

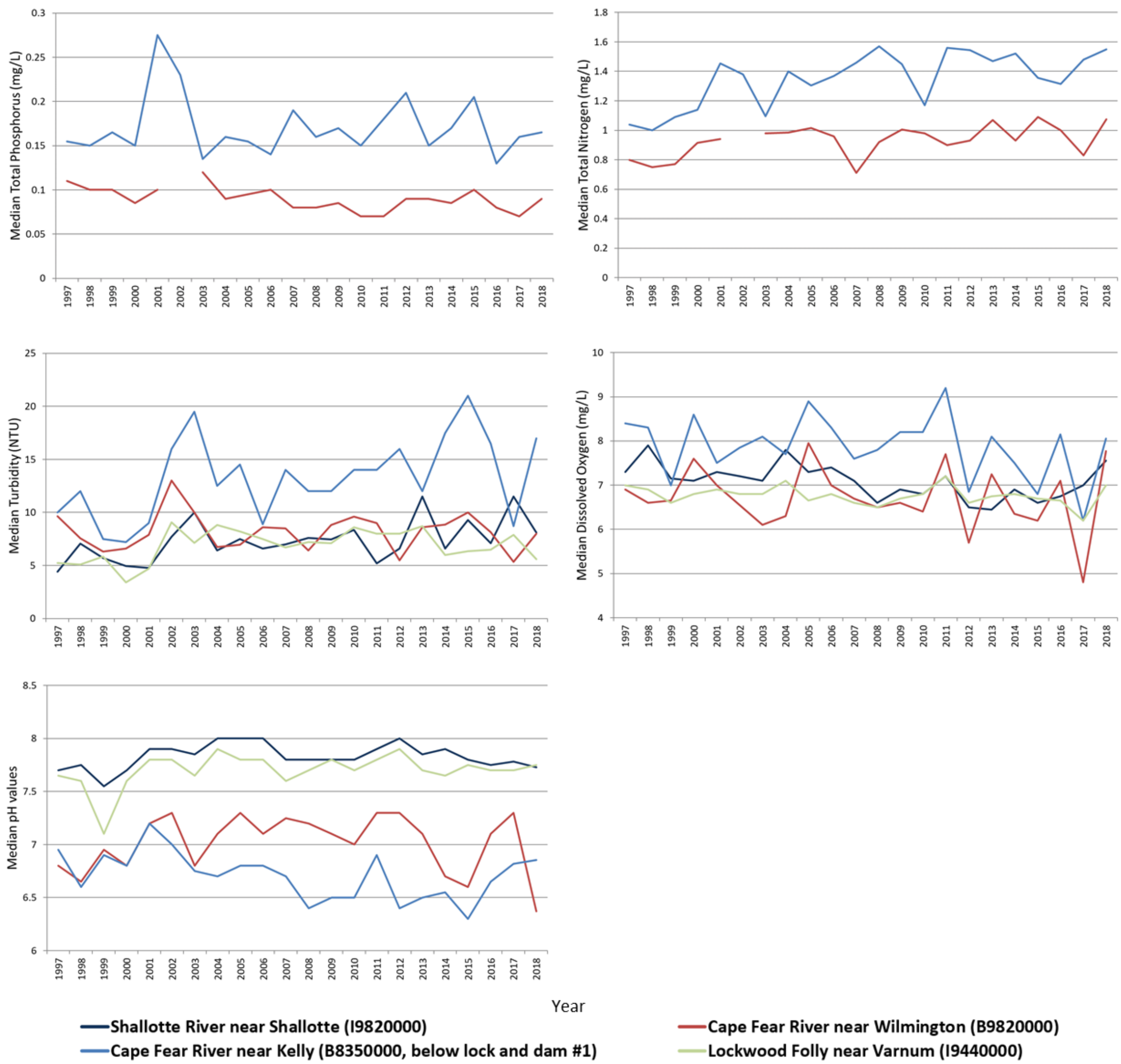

Figure X.8. Annual median Total Phosphorus (mg/L), total Nitrogen (mg/L), Turbidity (NTU), DO (mg/L), and pH values, and mean Chlorophyll a (µg/L) concentrations for five representative Ambient Monitoring System (AMS) stations in Coastal Habitat Protection Plan (CHPP) Region 4.

There is a general trend of increasing nutrients and Chlorophyll a coastwide, in almost every CHPP region. This is especially evident in the upstream AMS stations. Increases in turbidity, especially during wet years, are also being observed. Eutrophication and decreased water clarity due to increased turbidity, not only degrades water quality, but can lead to algal blooms and fish kills, as well as having detrimental effects on other coastal habitats such as SAV and oysters.

Toxic chemical contamination is not evaluated by DWR in estuarine and nearshore ocean waters. The current standards do not completely eliminate risk from toxins because: (1) values are not established for many toxic chemicals, (2) mixtures and breakdown products are not considered, (3) effects of seasonal exposure to high concentrations have not been evaluated, and (4) some potential effects, such as endocrine disruption and unique responses of sensitive species, have not yet been assessed.

Nutrient Sensitive Waters

Nutrient Sensitive Waters (NSW) is a supplemental classification intended for waters needing additional nutrient management due to excessive growth of microscopic or macroscopic vegetation. Currently, there are no water quality standards for nutrients, except 10mg/L nitrate for drinking water; nutrient enrichment is presently measured by chlorophyll *a* response in the water column. Four basins carry the supplemental classification of NSW, including all waterbodies in the Tar-Pamlico, Neuse, and Chowan river basins, and the New River in the White Oak Basin (i.e., Onslow Bay Basin). Nutrient Sensitive Waters are subject to nutrient reduction strategies for wastewater discharge limitations (T15A NCAC 2B .0223), and different nutrient management strategies, including stormwater and agriculture, as well as riparian buffer protection (15A NCAC 02B .0700 - .0715) are in place to help reduce nutrient loads in these waterbodies.

Chowan Nutrient Sensitive Waters Strategy

Algal blooms and subsequent fish kills in the Chowan River led to its NSW classification in 1979, with a nutrient control plan in 1982 calling for a basinwide reduction of 35% TP and 20% TN. Implementation to reduce nutrient loads by point sources included limits of 1 mg/L TP and 3 mg/L TN, and the conversion of many municipal point source discharges to land application non-discharge systems resulted in improved water quality. The basin was a priority for implementation of agriculture BMPs, reducing nutrient runoff. Data through 2012 did not indicate chlorophyll *a* levels exceeding standards in the Chowan River. The nutrient measures taken did result in water quality improvements for almost 30 years. During that time period, an increase in SAV occurred, an indicator of improved water quality.

However, since about 2015, the Chowan River has experienced a resurgence in recurrent summer algal blooms and harmful algal bloom (HAB) activity. Harmful algal blooms are those that produce toxic or harmful effects on people, aquatic organisms, or birds. These HABs have occurred mainly south of Harrellsville (near station D8356200) down to the Edenhouse Bridge (near station D9490000). Many of the blue-green algal bloom species detected have been identified as potentially harmful, such as *Dilochospermum* and *Microcystis*. The blooms evaluated in 2019 were widespread throughout the Chowan River system but were most intense from Indian Creek (Dillard Millpond) downstream to Rockyhock Creek. These intense blooms were associated with elevated microcystin cyanotoxin concentrations. In response, DEQ has issued press releases “urging the public to avoid contact with the green or blue water in the Chowan River due to algal blooms that have lingered in the area”.

The central Chowan River near Colerain is tracked by DWR as a coarse gauge of productivity trends for the basin. For the current draft Chowan River Basinwide Plan, DWR compiled biannually tabulated 5-year statistics for this station beginning in 2016; the results are provided in Table X.2 (https://deq.nc.gov/about/divisions/water-resources/water-planning/basin-planning/water-resource-plans/chowan/chowan).

Table X.2. Chowan River near Colerain, Chlorophyll *a* Integrated Report (IR) Summaries for IR 2016, 2018, IR 2020 (Draft) and IR 2022 (Partial; Missing Year 2020).

	Integrated Report Period			
	2016	2018	2020 (Draft)	2022* (Partial)
Mean Chl *a* Conc. (µg/L)	7.6	9.2	18.6	24.9
Number of Samples	50	45	45	33
Number > 40 µg/L Chl *a*	1	2	4	5
% > 40 µg/L	2	4.4	8.9	15.2
Integrated Report Date Window	2010-2014	2012-2016	2014-2018	2016-2020

*The data as of June 2020 for the partial 2022 IR is for 2016-2019. It is missing data for 2020. Final 2022 IR values will be different than what is presented here.

The DWR also analyzed longer-term temporal trends in nutrient loading for the current draft Chowan Basinwide Plan. While most nutrient parameters were generally unremarkable, a pronounced upswing was evident in Total Kjeldahl Nitrogen (TKN) concentrations and loads since about 2000 across most watersheds. The Chowan River Colerain station results are provided in Figure X.9 as illustrative of this TKN phenomenon, which is attributed to the organic nitrogen fraction.

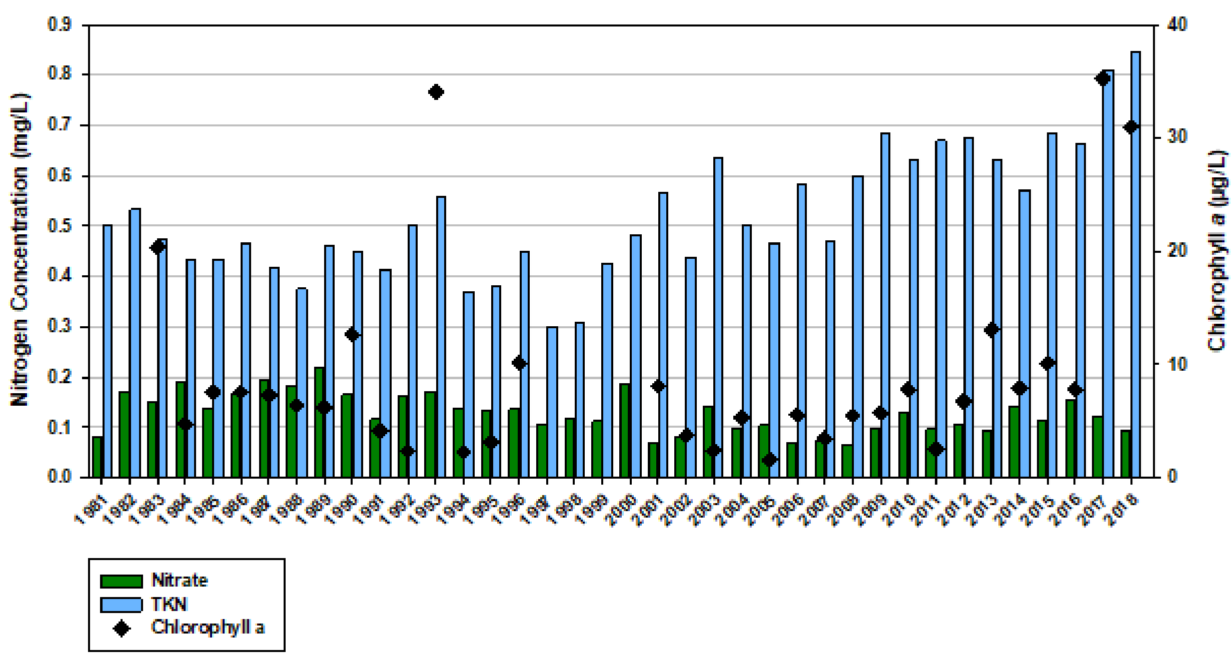

Figure X.9 Annual Mean Total Kjeldahl Nitrogen (TKN), Nitrate and Chlorophyll a Concentrations at the Chowan River near Colerain Ambient Monitoring System Station (D8950000.)

Tar-Pamlico Nutrient Sensitive Waters Strategy

The Tar-Pamlico Basin was classified as NSW in 1989. The basin has a TMDL goal to help meet chlorophyll *a* standards in the Pamlico estuary. Water quality data are assessed at Grimesland (O65600000) along the Tar River to determine whether or not nutrient levels in the Tar-Pam Basin are meeting standards, including reductions of 30% TN and not increasing TP from the 1991 baseline data. Trend analysis of the nutrient parameters data from 1991-2016 at Grimesland indicate an increase in total Kjeldahl nitrogen (TKN; which is total concentration of organic nitrogen and ammonia) and TN flow-normalized loads (Figure X.10; DWR unpublished). The organic nitrogen increase wholly offsets earlier decreases in nitrate loading. Interestingly, the flow-normalized TP loads showed a pronounced and unexplained rise and fall since 2010 (Figure X.11).

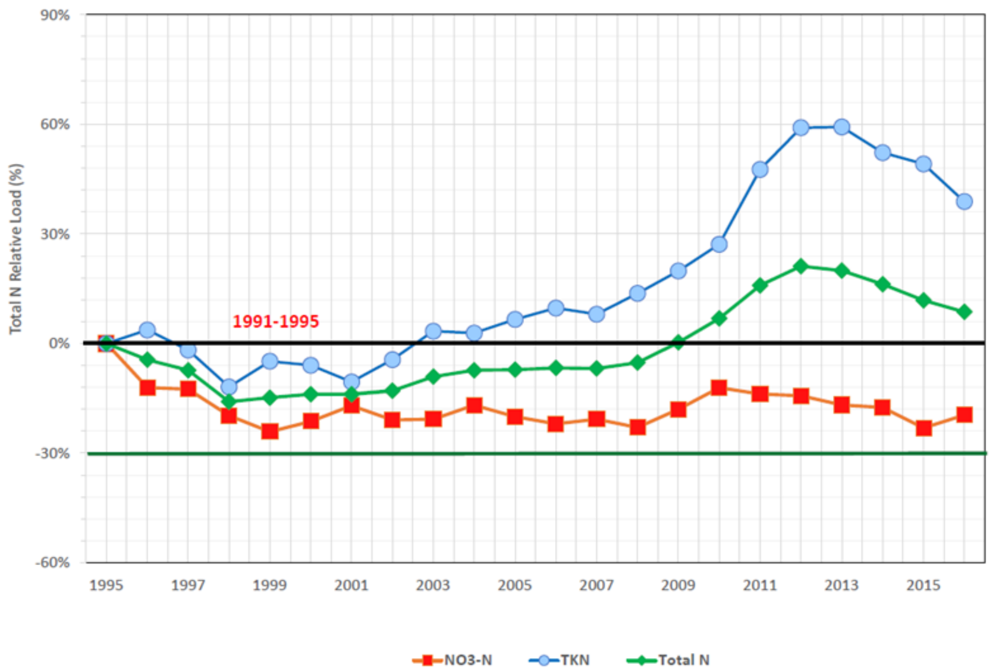

Figure X.10. Flow-normalized nitrogen loads, at the Tar River at Grimesland Ambient Monitoring System Station (O65600000; % Change vs. 1991-1995).

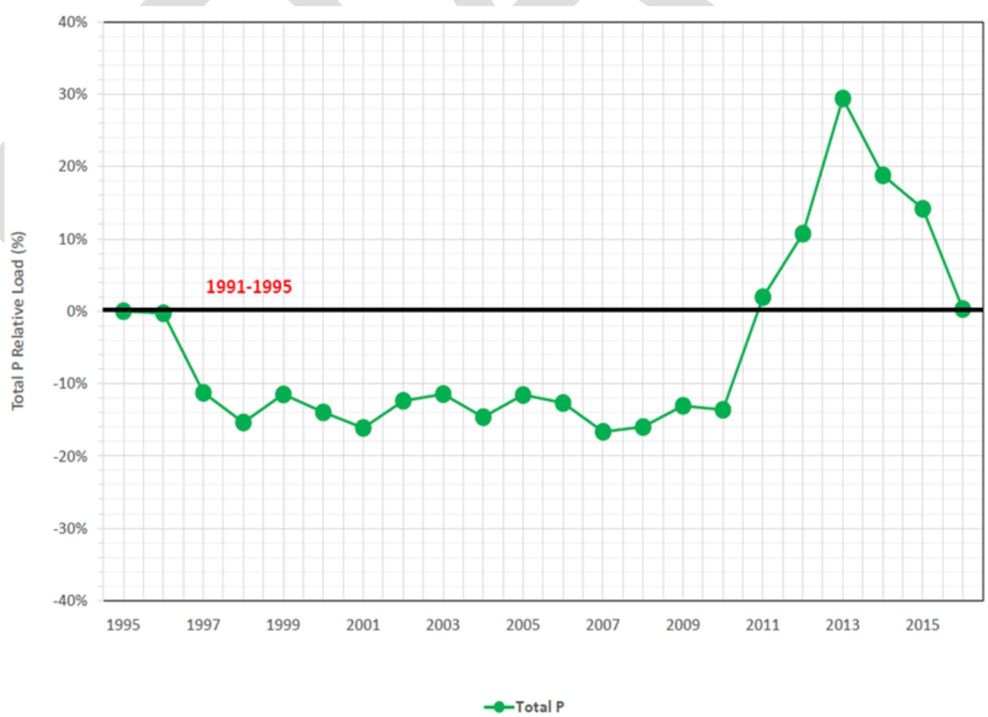

Figure X.11. Flow-Normalized Total Phosphorus Loads, at the Tar River at Grimesland Ambient Monitoring System Station (O65600000; % Change vs. 1991-1995).

Nutrient loading is flow dependent, with levels falling below baseline only during extreme low flows. The Tar-Pamlico and Neuse river basins indicate a rise in TKN, specifically organic nitrogen. The USGS LOAD ESTimator (LOADEST) tool was used to estimate TN and TP annual load time series at the compliance point in the Tar-Pamlico basin (NCDWR unpublished). Load assessments are impacted by precipitation as seen in 1996 (Hurricane Fran), 1999 (Hurricane Floyd) and 2003 (unusually wet year). The annual load time series of the Tar-Pamlico River at Grimesland shows that the load fell below the targeted TMDL goal of 3,000,491 lbs/yr in 2007, 2008, 2011. The LOADEST TP annual load time series at the same station fell below the targeted TP load of not-to-exceed 396,832 lbs/yr in 2007, 2008, 2010 and 2011. These were drought years as seen by the low flow at the USGS gage station.

Neuse Nutrient Sensitive Waters Strategy

The Neuse River Basin was classified as NSW in 1988. Data for the Neuse River TMDL requiring a 30% decrease in TN load from the 1991-1995 baseline is assessed at Ft. Barnwell. Data from 1991-2011 indicate decreasing trends in TN, TP, NH_3 and NOx concentrations, and an increase in concentrations of TKN. Portions of the Neuse River Estuary remain impaired due to nutrient enrichment.

Like the Tar-Pamlico, the Neuse river basins indicate a rise in TKN, specifically organic nitrogen, and the LOADEST tool was used to estimate TN at the Neuse River compliance point. Load assessments are impacted by precipitation as seen in 1996 (Hurricane Fran), 1999 (Hurricane Floyd) and 2003 (unusually wet year). The annual load time series for the Neuse River at Fort Barnwell indicates that only during the low flow years of 2001, 2002, 2005, 2007, 2008, 2011 and 2012 does the TN load at the compliance point fall below the TMDL target of <6,750,000 lbs/yr of TN.

The DWR's longer-term trend analysis, normalizing for the effects of flow, shows an upswing in organic nitrogen loading very similar to the other coastal watersheds since around 2000, as captured in TKN values. Figure X.12 illustrates this trend above the estuary near Fort Barnwell. Again, organic nitrogen loading increases wholly offset early nitrate decreases.

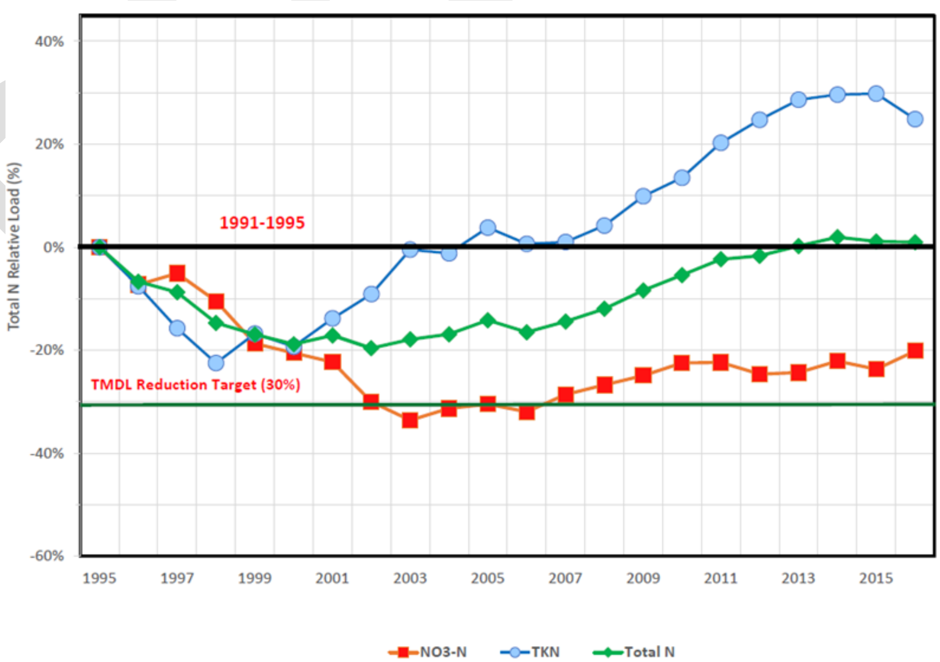

Figure X.12. Flow-Normalized Nitrogen Loads, Neuse River at Fort Barnwell Ambient Monitoring System Station (% Change vs. 1991-1995).

New River Nutrient Sensitive Waters Strategy

The New River was classified NSW in 1991. The strategy to reduce point source nutrients to the upper estuary include: TP and TN limits on existing discharges, and monitoring for TN and TP for facilities without limits. It was recommended that no new discharges be permitted, and expansions of existing facilities only be allowed if there is no increase in loading of oxygen-consuming waste. Ambient water quality data through 2018 indicate nutrient enrichment is still a problem in the upper New River Estuary resulting in continued excursions of the chlorophyll a standard (Figure X.13). The DWR White Oak River Basin Plan will be completed in 2021 and will include additional water quality assessments and possible recommendations to address nutrient contributions to the New River Estuary. The point source reduction only strategy has not resulted in sufficient nutrient reductions in the estuary. There is a need to understand the overall load reductions achieved from point sources and to initiate nutrient reductions from all nonpoint sources in the watershed.

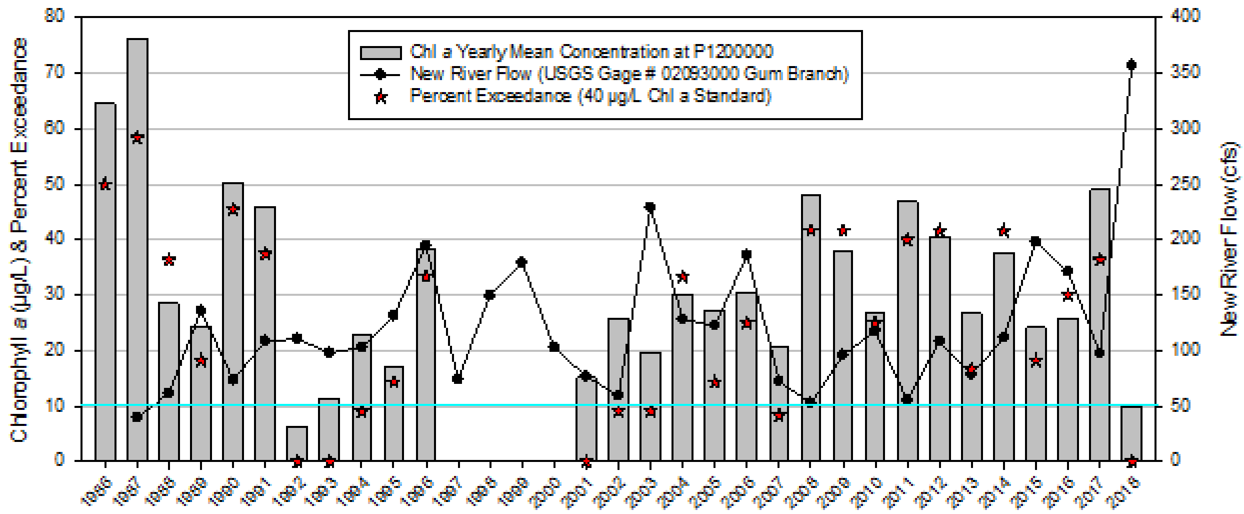

Figure. X.13. Annual Mean Chlorophyll *a* Concentrations at Station P1200000 (New River at Jacksonville US 17 Bridge) with Corresponding Percent Exceedance of the 40 µg/L Chlorophyll *a* Standard and Annual Mean New River Flow (blue line denotes the 10 percent excursion level).

Nutrient Criteria Development Plan

The DWR is currently revisiting nutrient-related water quality criteria statewide in accordance with the Nutrient Criteria Development Plan (NCDP). The plan was adopted in 2014 and last revised in 2019. The goal is to develop scientifically defensible criteria based on the linkage between nutrient inputs and the protection of designated uses. The first priority is to evaluate nutrient criteria for one specific water body within each of the three water body types. The development of these site-specific criteria will occur for the following water bodies in this order: 1) Reservoir/Lake - High Rock Lake, 2) Estuary – Chowan River/Albemarle Sound, and 3) River/Stream - Middle Cape Fear River.

Evaluation of nutrient-related criteria for the Chowan River and Albemarle Sound is currently underway. An initial evaluation process and identification of research needs were coordinated by the Albemarle-Pamlico National Estuary Partnership (APNEP) with a phase I report documenting those interim findings in 2018. The DWR, Scientific Advisory Council (SAC) members, and academic partners are currently filling those research gaps and continuing with the evaluation of nutrient criteria in this region. Both the

APNEP phase I report and more recent input from the SAC have identified linkages between potential nutrient-related criteria and the protection of water column and submerged aquatic vegetation habitats.

Fish Kills and Algal Blooms

Algal blooms occur when specific environmental conditions are met, such as increased nutrient (nitrogen and phosphorus) concentrations, increased water temperature, prolonged solar radiation, and stagnant water flows. These conditions can cause algae to grow rapidly ("bloom"), thus creating negative effects in the system, including decreased DO, increased pH levels, fish kills. They are aesthetically unappealing and if comprised of HABs, can impact health of humans and aquatic organisms. Not all algal blooms result in fish kills, and they are not the only cause of hypoxic conditions, however they are often related.

The number of reported algal bloom events along the NC coast varied annually from 2015 through 2019. During this time, the number of reported blooms reached a maximum in 2015 with 50 events and a minimum in 2017 with 25 events. Blooms are either reported by concerned citizens through the algal bloom reporting app or by DWR staff during routine monitoring. As with fish kills, investigations of bloom reports depend on the availability of field and laboratory staff to collect and analyze the samples. Even when an investigation does not occur, suspected bloom reports are recorded to help analyze overall trends in algal activity across the state.

Certain types of algae are also known to produce various taste and odor compounds as well as toxins, which can harm aquatic organisms, humans, and terrestrial animals that interact with the contaminated water (eg. dog drinking, bird feeding). DWR has the capabilities to test for *Microcystin*, a common toxin produced by bloom-forming algae known as cyanobacteria. In particular, the Chowan River and portions of the Pasquotank River basin including the Albemarle Sound has reported algal blooms since the 1970s. Blooms in these systems have increased in recent years, prompting DWR to begin evaluation of numeric nutrient criteria for the systems.

In 2019, DWR investigated 13 fish kill events across NC and provided reports under its investigation protocols (Figure X.14; NCDWR 2019). In addition, 64 sightings of fish kills or algal blooms were reported by the public to DWR via its online app. Some public sightings were accounted for in DWR reports, but much of the public information remained unconfirmed by DWR staff members. Confirmed and unconfirmed activity was reported during the year in 12 of the state's 17 major river basins and in 35 counties. Fish kill information for the current year is posted weekly from June to November on the DWR fish kill website: https://deq.nc.gov/about/divisions/water-resources/water-resources-data/water-sciences-home-page/nc-fish-kill-activity/fish-kill-events

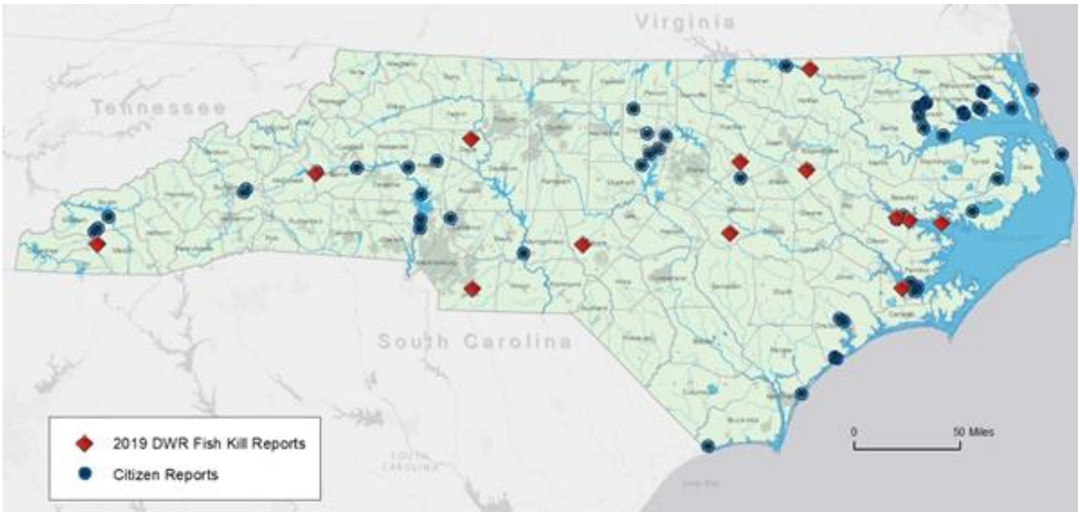

Figure X.14 Fish Kill Activity Reported in North Carolina during 2019. (Source: NCDWR 2019).

During 2019, DWR received 65 reports of fish kill or algal bloom activity from the public often via the mobile app (NCDWR 2019; Figure X.X.). Developed in 2016, the app has proven useful in notifying regional staff of possible fish kill activity and as a means for initial contact with regards to dead fish and related algal bloom sightings. Public reports were reviewed and forwarded as soon as possible to the appropriate regional office staff for further investigation. Less available oxygenated waters, termed habitat compression, has resulted in increased fish mortality in NC, due to algal bloom events as well as hurricanes (NCDEQ 2016), potentially pushing fish into less suitable habitat conditions or making them more vulnerable to predation. Habitat compression may be associated with a 10-50% worldwide decline of pelagic predator diversity (Stramma et al. 2012). Increasing occurrence of hypoxic or anoxic waters is problematic for the coastal habitats and the organisms that call them home.

Fish kill and algal bloom activity can be reported here:
https://survey123.arcgis.com/share/c23ba14c74bb47f3a8aa895f1d976f0d?portalUrl=https://ncdenr.maps.arcgis.com

Shellfish Sanitation and Recreational Water Quality (SSRWQ)

Various sections of DMF, including Fisheries Management, Habitat Enhancement, and Shellfish Sanitation and Recreational Water Quality (SSRWQ), also collect water quality data within the CHPP regions. The SSRWQ is responsible for monitoring and classifying coastal waters as to their suitability for shellfish harvesting and monitoring and issuing advisories for coastal recreational swimming areas. The Shellfish Sanitation Program is conducted in accordance with the guidelines set by the Interstate Shellfish Sanitation Conference (ISSC) contained in the National Shellfish Sanitation Program (NSSP) Guide for the Control of Molluscan Shellfish Model Ordinance. The NSSP is administered by the U.S. Food and Drug Administration and is based on public health principles to prevent human illness associated with the consumption of molluscan shellfish. To fulfill this purpose, the SSRWQ section performs water sampling at 968 shellfish growing area (SGA) stations.

All SGAs are surveyed every three years to document all existing or potential pollution sources, to assess the bacteriological quality of the water, and to determine the hydrographic and meteorological factors that could affect water quality. Water samples are collected at least six times a year from each SGA and are tested for fecal coliform bacteria, which are an indicator that human or animal wastes are present in the water. In addition, reviews of SGA bacteriological data and pollution sources are conducted annually. This information is then used to classify each SGA as either approved, conditionally approved open/closed, restricted or prohibited. Approved areas are consistently open to shellfish harvest while prohibited areas are permanently closed (Table X.3). Conditionally approved areas can be open to shellfish harvest under certain conditions. An area's status can change quickly due to temporary closures after significant rainfall resulting in runoff, high results during routine bacteriological sampling, or an unexpected pollution event (ex. sanitary sewer overflow, see Inflow and Infiltration issue paper for more details). The area remains closed until water sampling indicates a return to acceptable bacteria levels. Restricted waters can be used for harvest at certain times as long as the shellfish are subjected to further cleansing before they are made available for consumption. For the most up to date closures, refer to the Shellfish Sanitation Temporary Closure Public Viewer (https://ncdenr.maps.arcgis.com/apps/webappviewer/index.html?id=5759aa19d7484a3b82a8e440fba643aa).

Table X.3. Classification of shellfish growing areas (SGAs) in acreage from 2007-2020 from the Division of Marine Fisheries' (DMF's) Shellfish Sanitation and Recreational Water Quality Section.

	Open Area		Closed Area		
Year	Approved	Conditionally Approved Open	Conditionally Approved Closed	Prohibited	Restricted
2007	1,732,069	45,699	11,775	429,475	NA
2008	1,734,339	43,184	12,793	428,685	NA
2009	1,734,192	43,281	12,788	428,739	NA
2010	1,734,938	43,054	12,552	428,414	NA
2011	1,734,938	43,054	12,552	428,414	NA
2012	1,732,888	44,599	12,708	428,835	NA
2013	1,733,069	44,649	11,834	429,531	NA
2014	1,733,155	44,261	11,827	429,796	NA
2015*	1,418,373	43,849	11,739	745,169	NA
2016	1,416,960	44,785	12,008	745,597	NA
2017	1,414,709	44,425	12,209	747,759	NA
2018**	1,414,525	44,122	11,859	729,761	18,933
2019	1,414,877	43,217	12,721	730,550	20,260
2020	1,416,179	42,857	10,138	735,791	18,658

*314,710 acres administratively closed on 2/4/15 due to budget cuts and office closures.
**First year of use for Restricted classification. Previously these waters were included in our Prohibited classification.

The NC Recreational Water Quality Program began testing coastal waters in 1997 with the mission to protect the public health by monitoring the quality of NC's coastal recreational waters and notify the public when bacteriological standards for safe bodily contact are exceeded. The coastal waters monitored include the ocean beaches, sounds, bays, and estuarine rivers. The program tests water at 204 swimming sites approximately weekly during the swimming season from April through September. Similar to the Shellfish Sanitation Program these samples are tested for bacteria; general water quality parameters are also recorded. Instead of fecal coliforms, these samples are tested for *Enterococcus* bacteria, an indicator organism found in the intestines of warm-blooded animals. While it will not cause illness, its presence is correlated with organisms that can and it survives better in the higher salinities associated with the ocean beaches.

Additional monitoring for water quality and swimming advisories are collected by NGOs and academics along the coast. For example, Sound Rivers publishes weekly water alerts (https://soundrivers.org/swimguide/) and the Lower Cape Fear River program publishes yearly reports on the water quality of the Lower Cape Fear Watersheds (https://uncw.edu/cms/aelab/lcfrp/).

Other Water Quality Monitoring

The DMF has over 20 different sampling programs with coastwide spatial cover. Most DMF programs were already collecting abiotic environmental variables, such as temperature, salinity, DO, depth, sediment and bottom composition. In 2009, DMF modified monitoring programs to ensure those parameters were being accurately recorded, and to collect additional habitat metrics such as secchi depth, and shoreline alteration. While these are point in time measurements, they can be useful for looking at long term averages. For example, DMF program data, along with the AMS data and data provided by Wildlife Resources Commission (WRC), were used to make interpolated salinity maps for high, mean, and low flow years from 1988 to 2017 (Figures X.15 – X.X). High and low flow years were determined if the yearly mean was +/- two standard deviations from the time period mean.

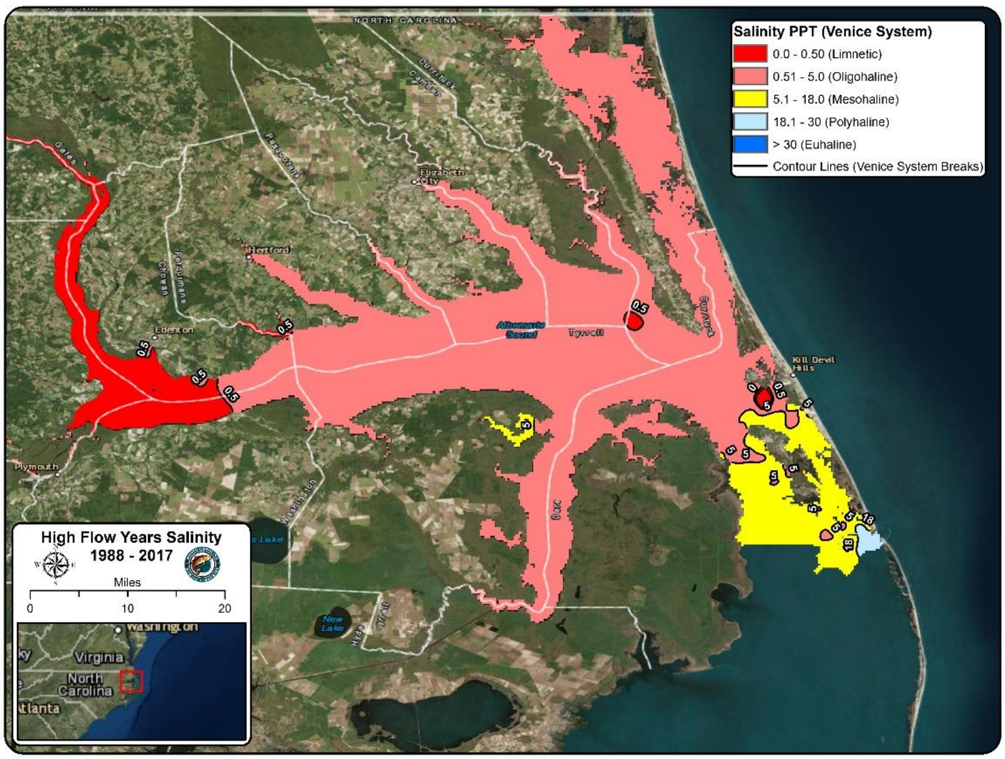

Figure X.15. Interpolated salinity maps for high flow years from 1988 to 2017 for CHPP region 1.

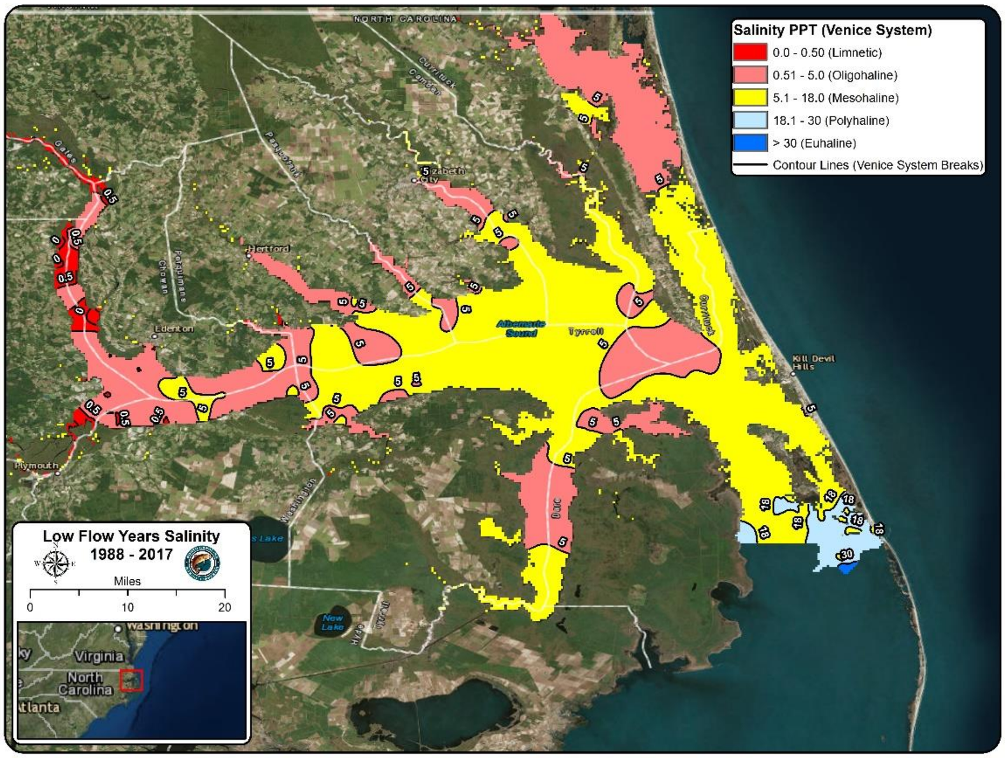

Figure X.16. Interpolated salinity maps for low flow years from 1988 to 2017 for CHPP region 1.

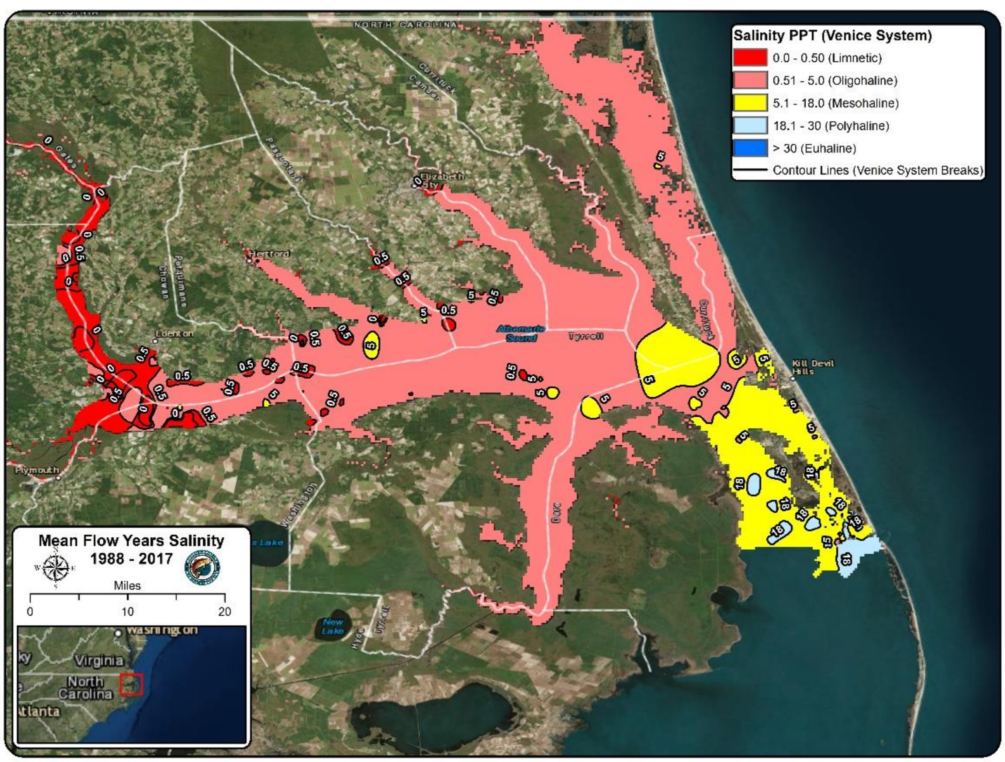

Figure X.17. Interpolated salinity maps for mean flow years from 1988 to 2017 for CHPP region 1.

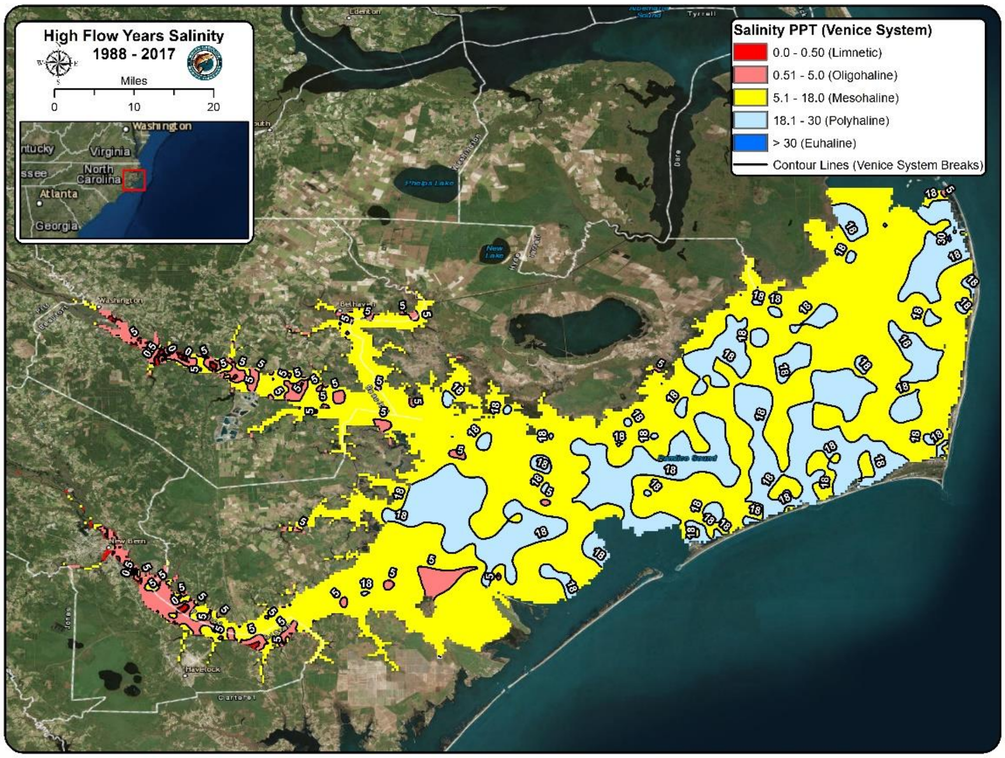

Figure X.18. Interpolated salinity maps for high flow years from 1988 to 2017 for CHPP region 2.

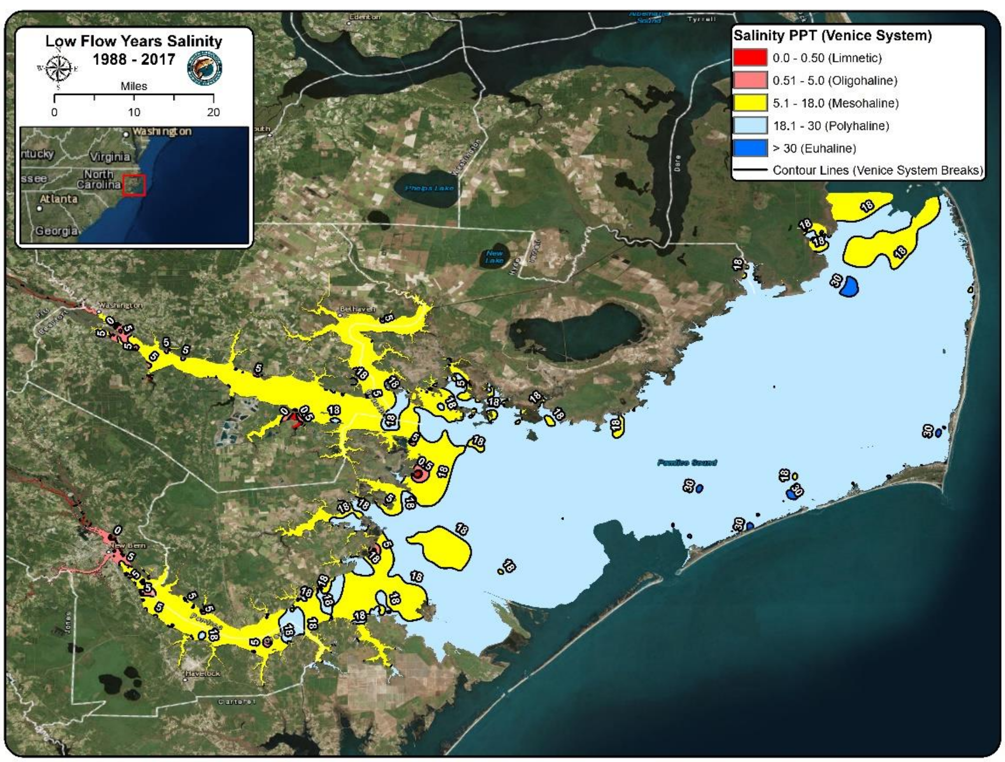

Figure X.19. Interpolated salinity maps for low flow years from 1988 to 2017 for CHPP region 2.

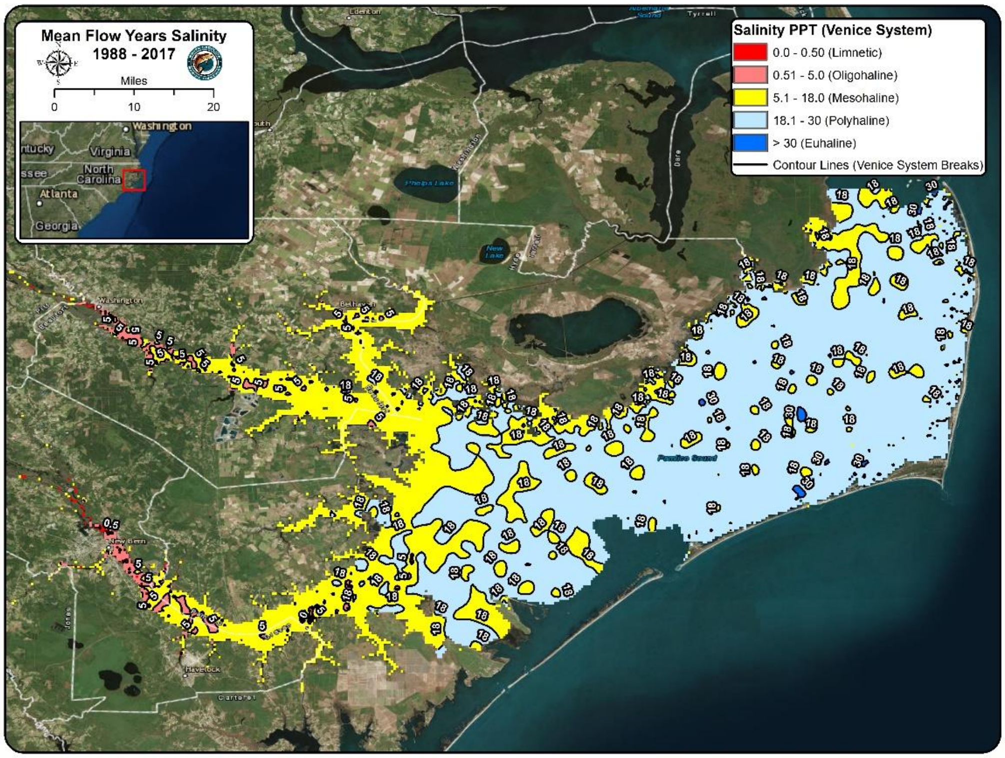

Figure X.20. Interpolated salinity maps for mean flow years from 1988 to 2017 for CHPP region 2.

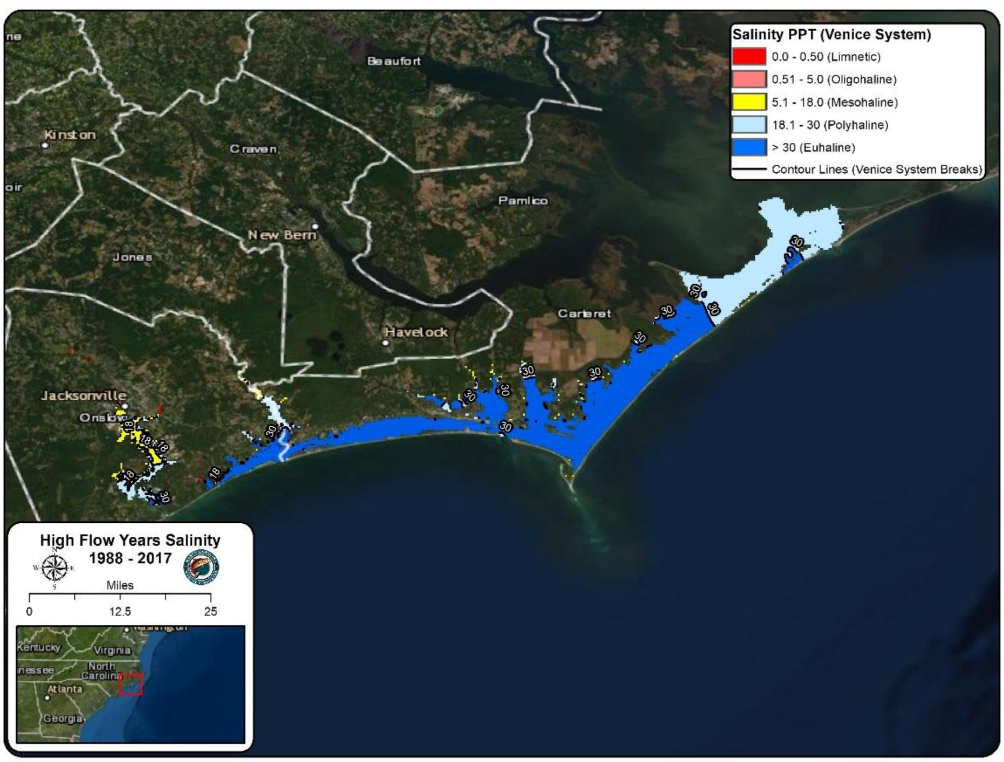

Figure X.21. Interpolated salinity maps for high flow years from 1988 to 2017 for CHPP region 3.

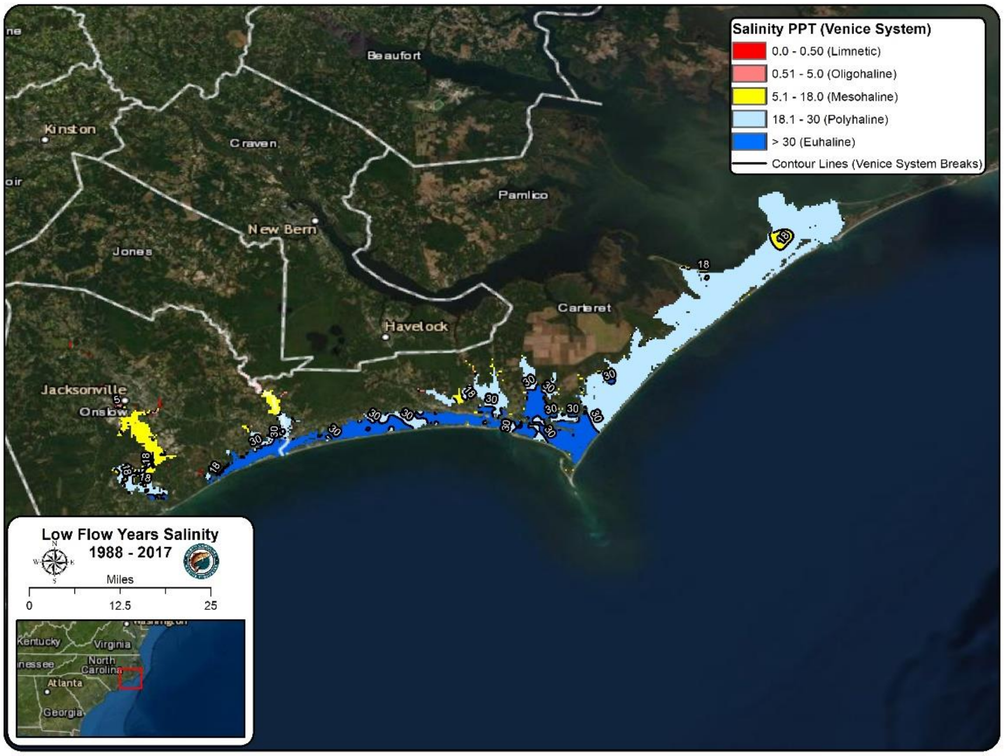

Figure X.22. Interpolated salinity maps for low flow years from 1988 to 2017 for CHPP region 3.

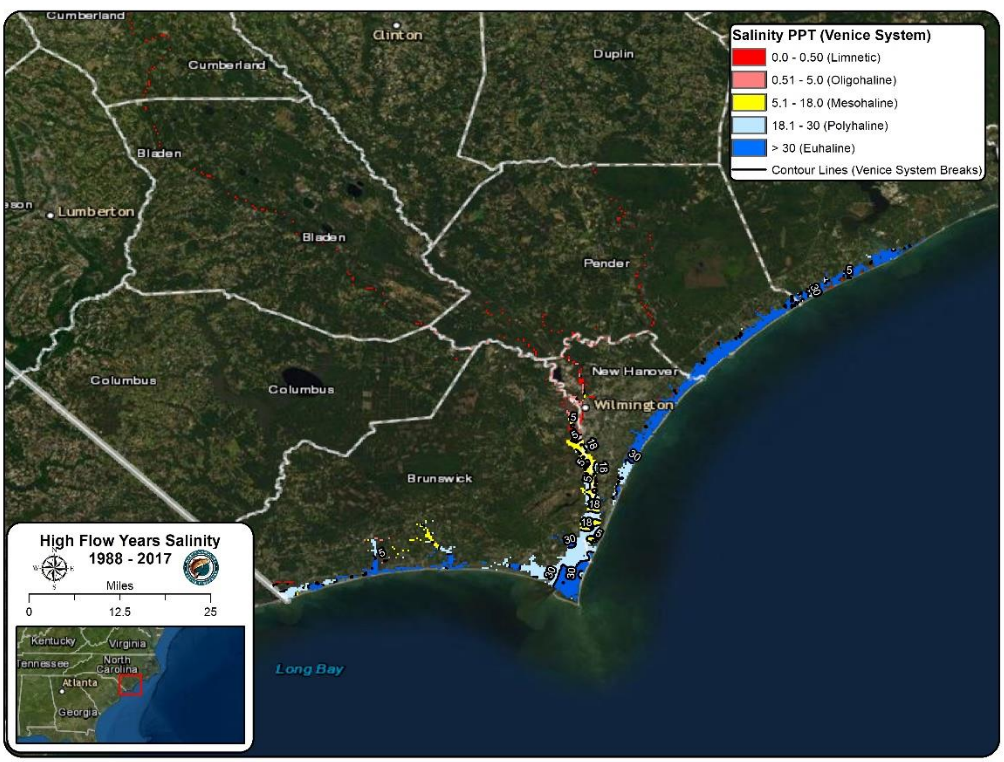

Figure X.23. Interpolated salinity maps for high flow years from 1988 to 2017 for CHPP region 4.

Figure X.24. Interpolated salinity maps for high flow years from 1988 to 2017 for CHPP region 4.

The DMF has used continuous water quality data sondes for the management of several programs. The Spotted Seatrout Cold Stun Monitoring Program, beginning in October 2015, deploys a coastwide array of 80 Onset HOBO Water Temperature Pro V2 loggers to collect water temperature data. The objective of this array is to monitor water temperatures that trigger cold stun events for spotted seatrout. Data loggers are deployed at 52 stations throughout the coastal rivers and creeks of NC to detect changes in water temperature throughout the year. If water temperatures in at least two spotted seatrout cold stun management areas met the triggers of 3°C for 24 hours and/or 5°C for eight consecutive days, and the DMF director closed the spotted seatrout commercial and recreational fishery temporarily. Data sondes that record additional parameters, including DO, have been used for river herring management and to assist with site selection and monitoring of oyster sanctuaries. These sondes require extensive maintenance however, and were discontinued in 2021 due to insufficient staff time and funds.

1.4.2. Shell Bottom

Shell bottom in NC has seen dramatic changes since colonial times when oyster reefs were so extensive along the coast they were a hazard to navigation (Newell 1988). For the purposes of the CHPP, shell bottom is defined as estuarine intertidal or subtidal bottom composed of surface shell concentrations of living or dead oysters (*Crassostrea virginica*), hard clams (*Merceneria merceneria*), and other shellfish (Street et al. 2005) and is limited to estuarine waters (NCDEQ 2016). Healthy oyster reefs are vital to the estuarine ecosystem, providing three dimensional structure for fish and important ecological services such as particulate and nutrient filtration, shoreline stabilization, and benthic habitat for fish, shrimp, and other invertebrates (Posey et al. 1999; Mann 2001; Peterson et al. 2003; Soniat et al. 2004; NCDEQ 2016). While oysters provide the major fish habitat from shellfish, hard clams and bay scallops contribute shell material to shell hash.

The eastern oyster occupies a unique position in the estuaries of NC because its colonization of estuarine bottom creates a productive habitat and the animal itself is harvested as a food item. Due to the combined effects of habitat destruction, overfishing, disease, and deteriorated water quality, eastern oyster populations have experienced tremendous declines world-wide, particularly within subtidal oyster reefs that occur along the mid-Atlantic coastline of the United States (Ault et al. 1994; Hargis and Haven 1988; Rothschild et al. 1994; NCDMF 2001). A 2011 study that examined the condition of oyster reefs across 144 bays and 44 ecoregions estimated that 85% of oyster reefs have been lost globally. Additionally, this study found that most of the world's remaining wild capture of native oysters (> 75%) comes from just five ecoregions in North America, yet the condition of reefs in these ecoregions is poor at best, except in the Gulf of Mexico (Beck et al. 2011). The historical losses of oyster reefs in North Carolina, primarily in the Pamlico Sound region, has been summarized and historical distributions have been documented (Winslow 1889; Street et al. 2005; NCDMF 2001, 2008, 2017; NCDEQ 2016).

<u>Commercial Harvest</u>

The need for extensive shellfish management in NC has been recognized since the 1947 NC General Assembly authorized the Division of Commercial Fisheries to conduct a rehabilitation program to restore the declining oyster fishery. Although the Fisheries Management Section of DMF has been actively managing these shellfish resources since 1964, it has done so with limited resource base information. In NC, commercial oyster landings from public bottom have been variable, but have been in general decline for most of the past century (NCDMF 2017). The decline in the oyster stock was likely initiated by poor harvesting practices resulting in overharvest and low spawning stock biomass, but compounded by habitat disturbance, pollution, and biological and environmental stressors including disease and storm damage. In the past decade, landings from private bottom aquaculture have increased significantly due to more interest in shellfish aquaculture industry with oyster aquaculture landings eclipsing wild harvest landings for the first time in 2017. Yet, there are insufficient data to conduct a traditional stock assessment for the eastern oyster in NC (Bowling et al. unpublished, 2021); therefore, population size and rate of removals from the wild oyster population are not known.

Management Monitoring

Shellfish management by DMF includes monitoring and managing natural harvest (cultch planting program), enhancing oyster habitat to increase larval recruitment (oyster sanctuary program), shellfish habitat mapping, and shellfish leasing. Monitoring is conducted in association with management activities. Supplement A to the Oyster FMP Amendment 2 established the trigger for closing areas to mechanical harvest to protect the resource and habitat, which was approved to continue under Amendment 4 of the Oyster FMP (NCDMF 2010; NCDMF 2017). Sampling efforts targets areas and oyster rocks that are fished by commercial oystermen, directly before the opening of and throughout the mechanical harvest oyster season. Only areas where commercial oystermen are working are sampled to determine localized depletion and address habitat protection.

Sampling began in September 2009 with pre-season oyster sampling using mechanical harvest methods. Sampling has consistently continued with a target of 10 sites per management area, throughout the four management areas. More intensive sampling is conducted if samples are near the trigger percentage. Sampling continues after an area is closed to assess the possibility of reopening. Sampling is discontinued when it is apparent that reopening is not likely to occur. This sampling is not intended for use as a species abundance index, but instead to reflect the conditions of the habitat during the open oyster mechanical harvest season to determine closure of an area as a protection measure. The 2012 to 2019 mechanical harvest season trigger sampling revealed low abundance and percent legal in all mechanical harvest management areas.

Oyster Sanctuaries and Cultch Planting Programs

To combat the generally declining trends of shellfish, shellfish habitat restoration efforts have been occurring throughout NC's estuarine waterbodies for over half a century. The Shellfish Rehabilitation Program, which began in 1947, has contributed to the restoration of depleted oyster grounds through the planting of cultch material and seed oysters (Chestnut 1955; Munden 1975; Munden 1981). State-sponsored cultch plantings began in 1915. The primary purpose of DMF cultch planting (Program 610) and oyster sanctuary (Program 611) programs is oyster fishery enhancement, which provides temporary habitat value as well as fishery benefits. These efforts also increase the co-benefits of the ecosystem services oysters provide, including water filtration and shoreline protection against waves and storms. As of 2020, DMF has constructed 15 oyster sanctuaries in the Pamlico Sound, totaling 396 permitted acres, and annually deploys several thousand bushels of cultch rock strategically throughout the estuaries of NC (Figure X.25). Since standard record keeping began in 1980, the Habitat Enhancement section of DMF has planted over 12 million bushels of cultch (NCDMF unpublished data).

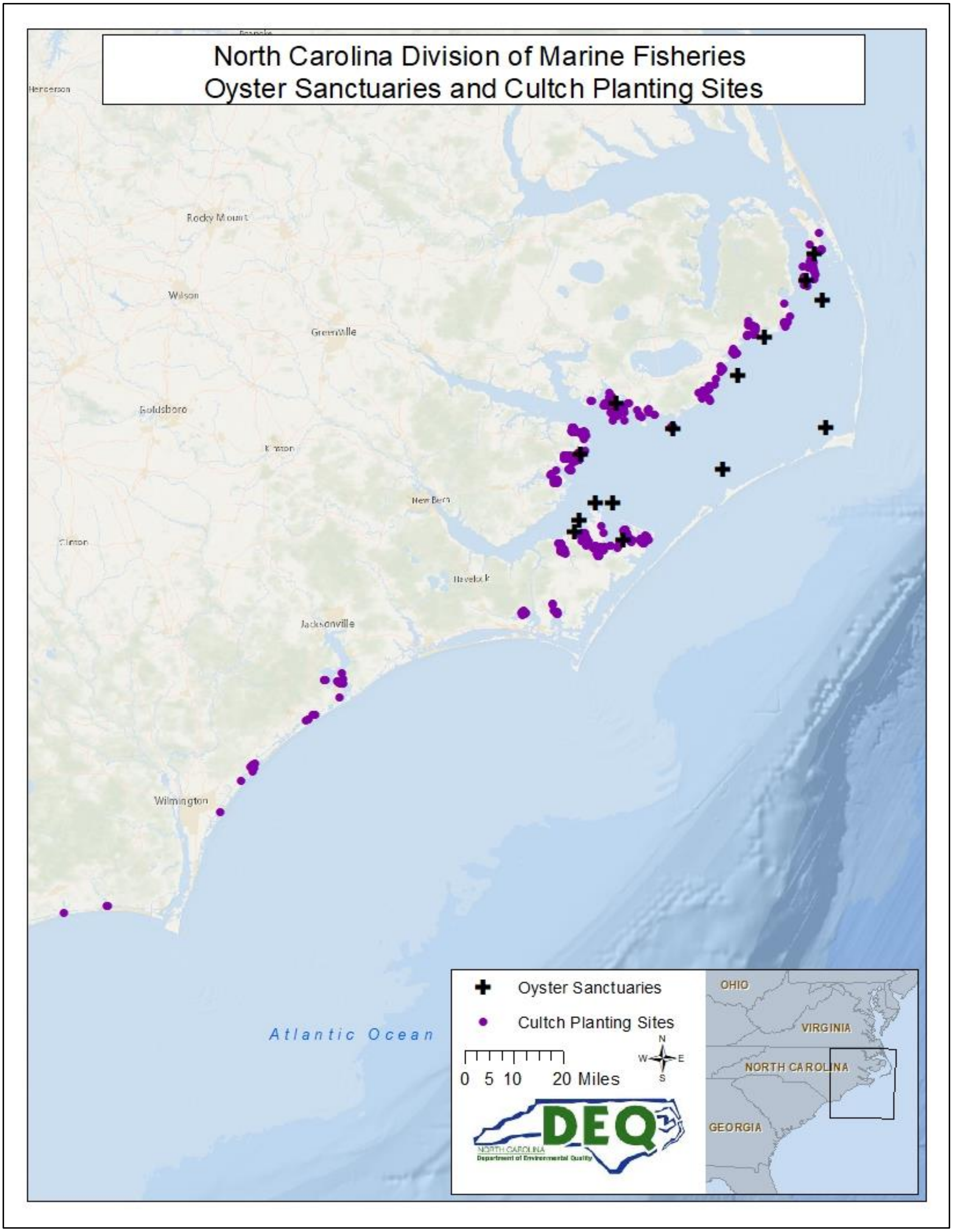

Figure X.25. North Carolina Division of Marine Fisheries Oyster Sanctuaries and Cultch Planting Sites.

Monitoring occurs at both oyster sanctuaries and cultch reefs to evaluate reef performance and potential for contribution to the state's fishery and benthic oyster habitat. Generally, oyster sanctuaries are evaluated annually for oyster densities, size frequencies, and population demographics via quadrat material extraction and subsequent oyster measurements. Cultch sites are sampled annually for three years, post-construction, using a mechanical dredge survey to track oyster settlement and growth towards suitable densities of harvestable oysters. Both reef types are additionally evaluated opportunistically via side scan to provide a metric of material persistence and reef rugosity through time. However, monitoring and site selection methods are currently evolving.

North Carolina oyster sanctuaries have demonstrated the capacity to maintain higher population density and greater abundance of large, fecund oysters in comparison to non-protected oyster reefs. Based on data collected from 2011-2014, oyster sanctuaries generally become "established" as oyster recruitment densities start high (~200 oysters/m^2), then generally settling around a density that can be supported within the body of water the reef is located. Many of the sanctuaries within the network are considered stable, with annual fluctuations reflecting recruitment and survival year to year. Newer oyster sanctuaries like Raccoon Island and Swan Island are still exhibiting larger densities of live spat, sublegal, and legal oysters (Figure X.26). When comparing no-take to unprotected oyster reefs, there is a striking decrease in densities. Oyster Sanctuary mean density is approximately 72 oysters/m^2 which is eight times higher mean oyster recruitment in natural reefs and approximately 12 times higher in cultch-planted reefs. The average reproductive potential per square meter of oyster sanctuaries can also be up to 30 times greater than unprotected reefs (Mroch et al. 2012; Puckett and Eggleston 2012; Peters 2014; Peters et al. 2017). Integrating total reef area and reproductive potential per square meter, oyster sanctuaries potentially provide 26.2% of all larvae to the system while accounting for 1% of reef area.

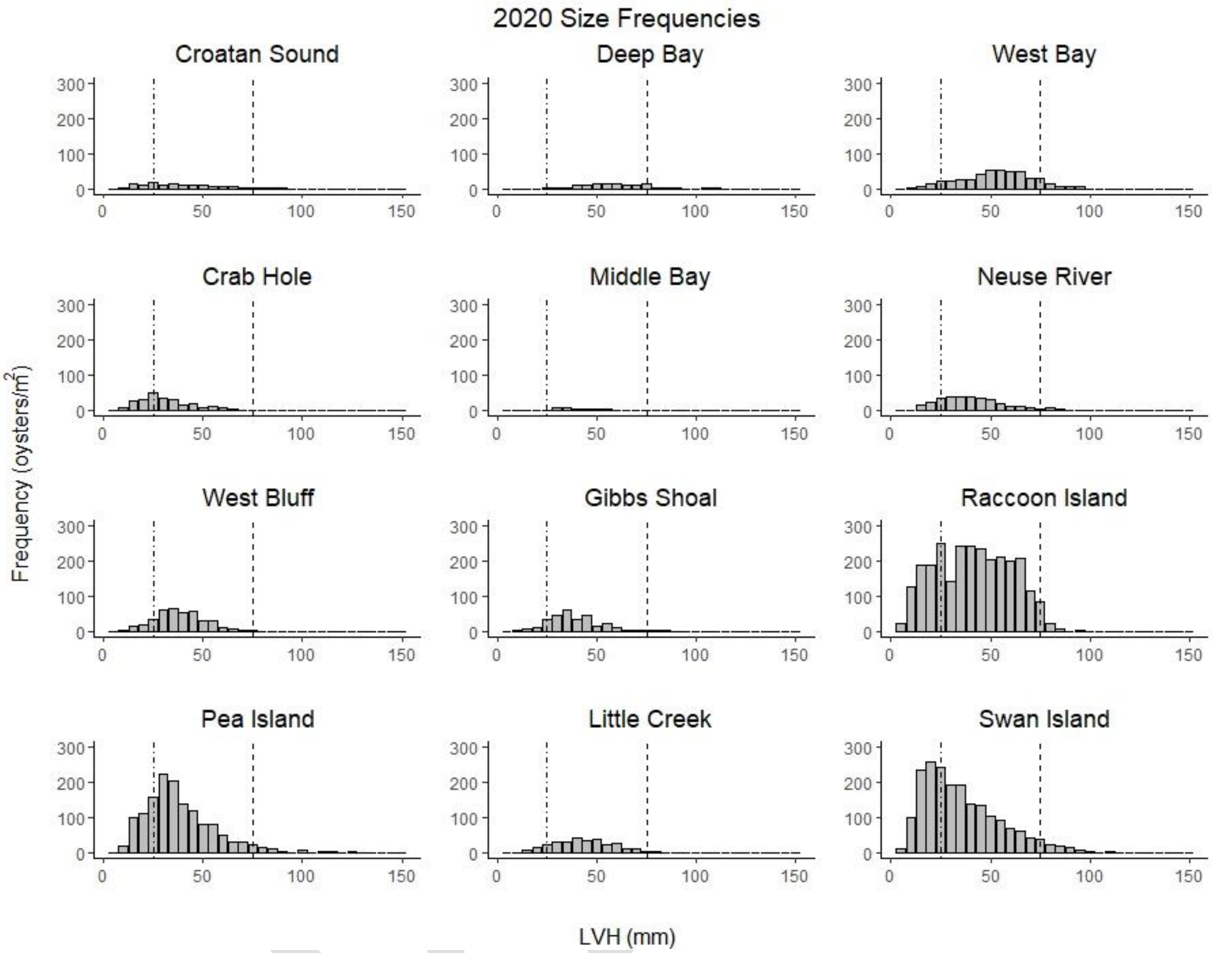

Figure X.26. North Carolina Division of Marine Fisheries 2020 Oyster Sanctuary sampling length frequency data.

Oyster recruitment (spatfall) on newly deployed cultch can be an indicator of potential larval availability and recruitment potential. The spatfall data (Program 610) from cultch planting sites over the past 31 years indicate a decline in maximum spatfall relative to similar surveys in the 1950s (Chestnut 1955; NCDMF 2014). During the 1990s, average oyster spat per shell (spatfall) in Pamlico Sound declined considerably, representing less than half the number of spat per shell recorded during the 80s (NCDMF 2008). From the late 1990s to the mid-2010s, spatfall showed a pronounced increase, surpassing 1980s spat densities. However, for the past five years there has been an overall declining trend, with the 2018 and 2019 indices being the lowest, falling below the 10-year average (annual average number of spat across all sampling sites; NCDMF 2020).

From 1980 to 2000, annual spatfall from north and south of Newport River has been somewhat variable from year to year, but generally stable overall (Figure X.27). In the early 2000s, both regions saw increases in spatfall densities. The southern region continued to see increased spatfall densities through the mid-2010s and has been declining since. The northern region densities peaked around 2010 and have also been declining, but has since seen a slight increase in the last few years. Some researchers suspect that subtidal oysters in Pamlico Sound are becoming spawner-limited, while others attribute the decline to stress and mortality from infectious diseases and poor water quality, including hypoxia due to nutrient rich runoff following intense rain and storm events, or physical damage from fishing activities (Choi et al. 1994; Lenihan et al. 1999; NCDMF 2008).

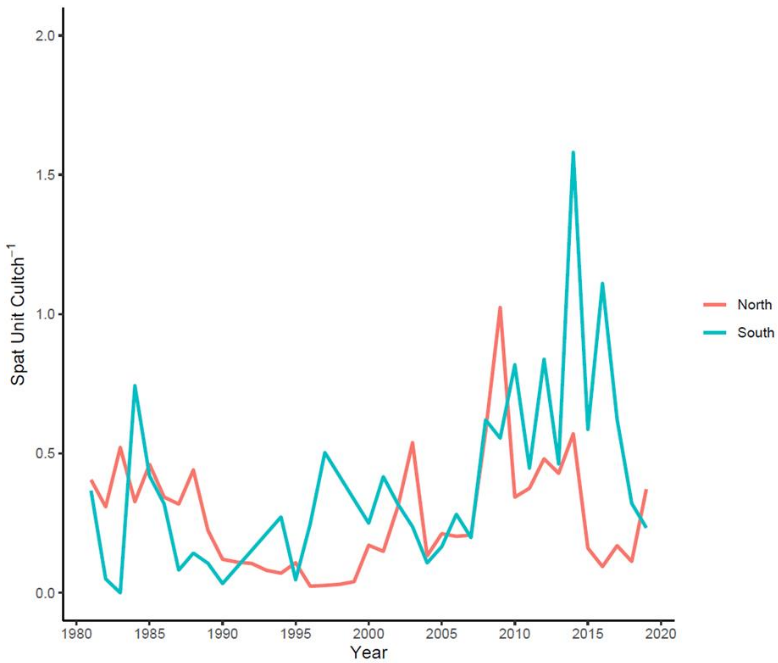

Figure X.27. The NC Division of Marine Fisheries (DMF) cultch sampling annual spatfall (average number of oyster spat per cultch unit) in northern and southern coastal waters (southern district includes from Newport River to South Carolina), 1980-2020. (Source: NCDMF Habitat and Enhancement Section, Program 610, unpublished data).

Extent in North Carolina

Estuarine Bottom Mapping Program

The first large scale shellfish bottom survey in NC waters was done by the US Navy in the late 1880s, but was limited to the larger estuaries (Winslow 1889). This survey was targeted solely toward oysters and potential oyster producing grounds and found that nearly 700,000 acres of potentially productive oyster bottom existed in NC. Although it was quite extensive survey, it is now outdated. In the early 2000s, a study revisiting this surveyed oyster bottom found many once-productive high profile reefs consisted of low profile shell rubble, low density reefs, or buried reef (Ballance 2004). It was also reported that the larger solid reefs had less live oysters, attributed to the ease of locating by fishermen. Anecdotal information and DMF sampling have noted that sediment has buried oysters in some locations that were once abundant, including the northeast side of the Neuse River, and Newport and North rivers.

In 1978, DMF began a shellfish bottom survey of the commercial shellfish-producing waters in the coastal area. The purpose of the survey is to locate and map shellfish-producing areas and to delineate potentially productive benthic shellfish habitats. The objectives include: 1) summarizing existing shellfish information and evaluate shellfish producing habitat based on environmental and utilization criteria; 2) surveying shellfish habitats to obtain baseline data and production potential information; 3) defining and delineating existing and potential shellfish habitat through a series of resource maps; and 4) providing for better utilization of the estuarine resources through improved information for management and increased public awareness.

A preliminary survey of the Newport River system was conducted from November 1980 to April 1981. Newport River was selected as a testing ground for survey techniques because of its close proximity to sampling headquarters, its diverse fisheries and environmental characteristics, and the pressing need for resource base data in that system. From this survey it was deemed that the mapping techniques and survey methods proved acceptable, and in 1987 the estuarine waters were divided into areas based on shellfish habitat suitability criteria. In 1989, based off the pilot study data, the Shellfish Resource Mapping Proposal was introduced which led to the creation of the Shellfish Mapping Program (Program 635) in 1990. From 1990 to 2019, this program mapped the shellfish habitat of the coast of NC from Roanoke Sound to the SC line. Along with the delineation of bottom types, gross determinations of shellfish concentrations within productive bottom types were determined through a stratified random sampling program. In 2019, the mapping of 567,691 acres of the intended 589,071 acres of coastal waters delineated into 24 bottom type strata was completed (Tables X.4-X.5 and Figures X.28-X.X).

Table X.4. Acreage and percentages of bottom habitat mapped by NC Division of Marine Fisheries (DMF) Estuarine Bottom Mapping Program (1990-2019).

CHPP Regions*	Area Intended for Mapping	Acres Mapped**	Percent Mapped	Total Mapped Shell Bottom Acres	Total Mapped Shell Bottom Percent	Mapped Subtidal Shell bottom Acres	Mapped Subtidal Shell bottom Percent	Mapped Intertidal Shell Bottom Acres	Mapped Intertidal Shell Bottom Percent
Albemarle Sound to Northeastern Coastal Ocean (1)	64,810	64,918	100%	615	2.79%	571	3.42%	44	0.82%
Pamlico Sound System (2)	278,477	286,890	103%†	4,290	19.45%	4,213	25.21%	77	1.44%
White Oak River Basin (3)	200,697	170,973	85%	10,543	47.79%	9,123	54.60%	1,420	26.53%
Cape Fear River Basin (4)	45,088	44,820	99%	6,612	29.97%	2,801	16.76%	3811	71.21%
Total	589,071	567,601	96%	22,060		16,709	75.74%	5,351	24.26%

*Oregon Inlet acres included in Albemarle Region; Ocracoke Inlet acres included in White Oak River Basin Region.
**Excludes areas that cannot be mapped due to military prohibitions, leases, bridge restrictions, depths, hazards.
† More are then intended was mapped.

Table X.5. Acreage of estuarine bottom habitat by 24 bottom type strata (strata) mapped by NC Division of Marine Fisheries (DMF) Estuarine Bottom Mapping Program (1990-2019) by Coastal Habitat Protection Plan (CHPP) regions and coastwide.

	Acreage				
Strata Description	Coastwide	Region 1	Region 2	Region 3	Region 4
Subtidal Soft Vegetated Shell (A)	0.00	0.00	0.00	0.00	0.00
Subtidal Soft Vegetated w/o Shell (B)	1,289.99	0.55	1,141.96	147.48	0.00
Subtidal Soft Non-vegetated Shell (C)	1,133.98	1.57	570.20	551.20	11.00
Subtidal Soft Non-vegetated w/o Shell (D)	62,805.95	1,248.17	43,462.40	14,748.24	3,347.13
Subtidal Firm Vegetated Shell (E)	332.83	0.31	1.04	331.48	0.00
Subtidal Firm Vegetated w/o Shell (F)	2,228.26	63.35	547.52	1,617.39	0.00
Subtidal Firm Non-vegetated Shell (G)	10,046.30	143.72	3,044.39	4,898.26	1,959.93
Subtidal Firm Non-vegetated w/o Shell (H)	68,806.89	7,131.24	26,924.92	26,335.82	8,414.92
Subtidal Hard Vegetated Shell (I)	128.40	4.27	9.29	114.84	0.00
Subtidal Hard Vegetated w/o Shell (J)	89,064.00	1,141.70	72,519.98	15,402.32	0.00
Subtidal Hard Non-vegetated Shell (K)	5,067.10	421.14	588.14	3,227.65	830.18
Subtidal Hard Non-vegetated w/o Shell (L)	281,907.43	53,637.12	136,179.86	86,002.24	6,088.21
Intertidal Soft Vegetated Shell (M)	11.59	0.00	0.00	0.00	11.59
Intertidal Soft Vegetated w/o Shell (N)	41.74	0.00	0.00	25.31	16.43
Intertidal Soft Non-vegetated Shell (O)	65.23	0.00	0.00	21.85	43.37
Intertidal Soft Non-vegetated w/o Shell (P)	750.49	0.00	0.00	146.37	604.11
Intertidal Firm Vegetated Shell (Q)	459.25	0.08	3.70	388.02	67.45
Intertidal Firm Vegetated w/o Shell (R)	27,191.33	75.63	96.82	13,605.80	13,413.07
Intertidal Firm Non-vegetated Shell (S)	2,904.83	0.00	1.36	401.76	2,501.71
Intertidal Firm Non-vegetated w/o Shell (T)	4,386.25	1.52	6.13	208.73	4,169.87
Intertidal Hard Vegetated Shell (U)	219.50	5.07	2.91	137.18	74.34
Intertidal Hard Vegetated w/o Shell (V)	2,647.01	778.92	1,276.41	418.15	173.53
Intertidal Hard Non-vegetated Shell (W)	1,616.69	38.60	69.26	470.83	1,038.00
Intertidal Hard Non-vegetated w/o Shell (X)	4,496.02	224.90	443.92	1,772.38	2,054.82
Total	567,601.05	64,917.88	286,890.21	170,973.30	44,819.66

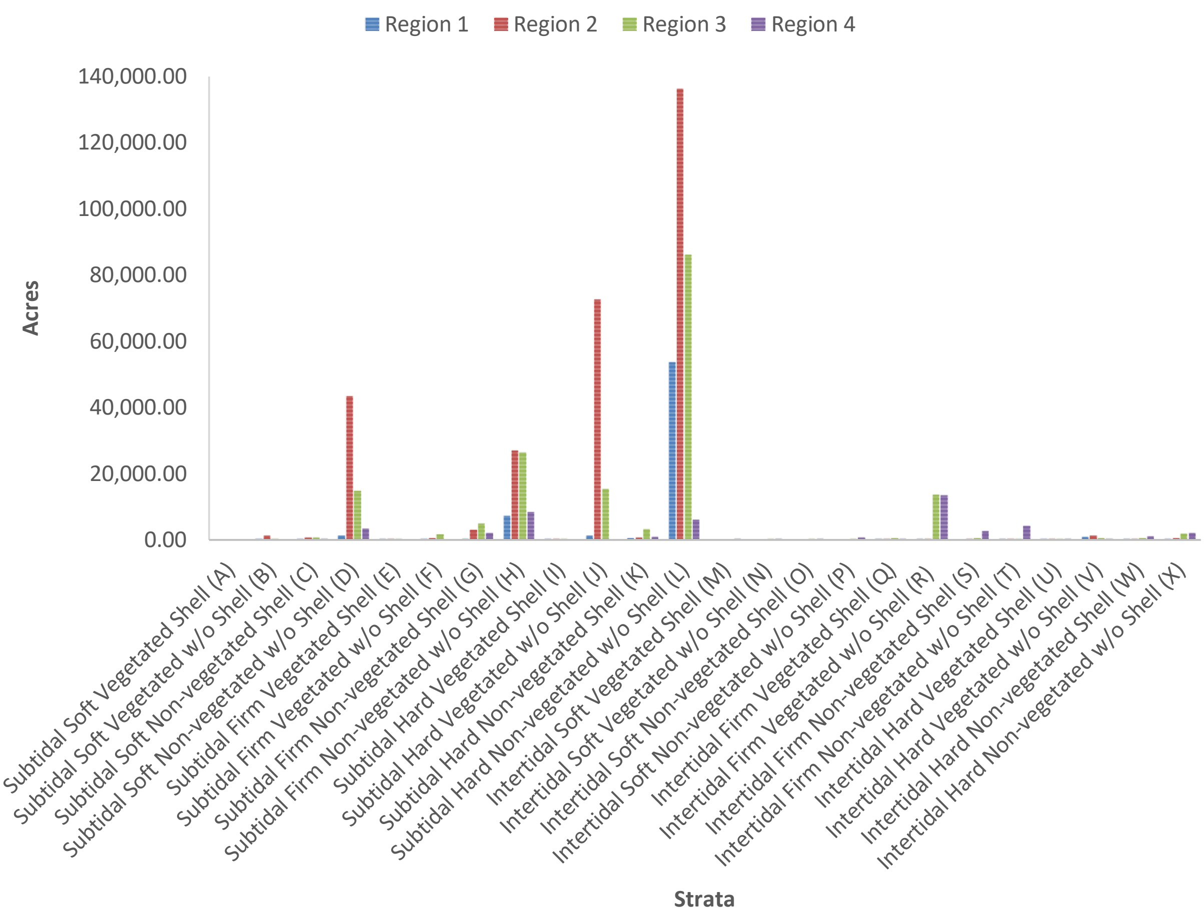

Figure X.28. Acreage of estuarine bottom habitat by strata mapped by NC Division of Marine Fisheries (DMF) Estuarine Bottom Mapping Program (1990-2019) by Coastal Habitat Protection Plan (CHPP) regions.

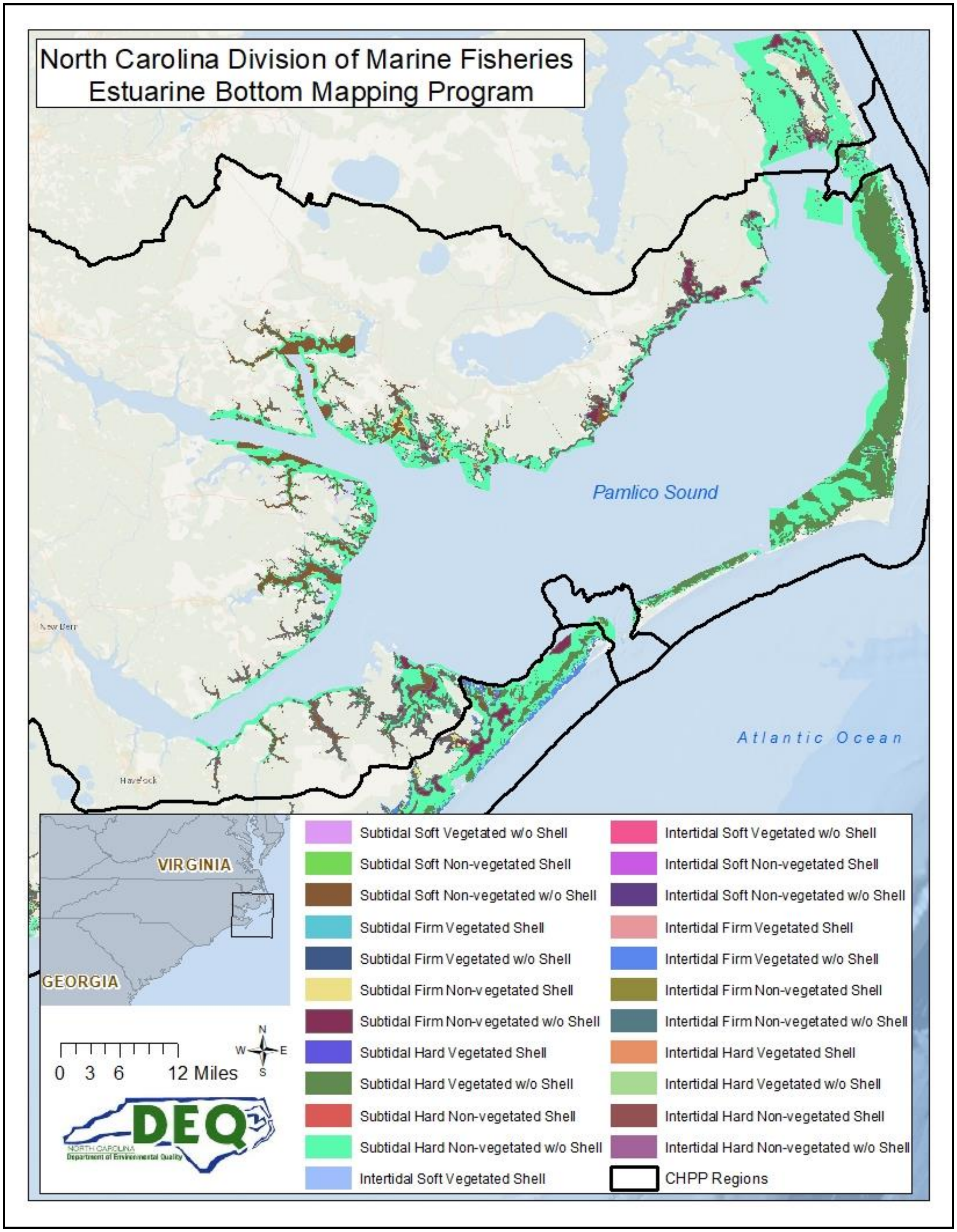

Figure X.29. The North Carolina Division of Marine Fisheries (DMF) Estuarine Bottom Mapping Program (1990-2019) strata for the northern Coastal Habitat Protection Plan (CHPP) regions 1, 1/2, and 2.

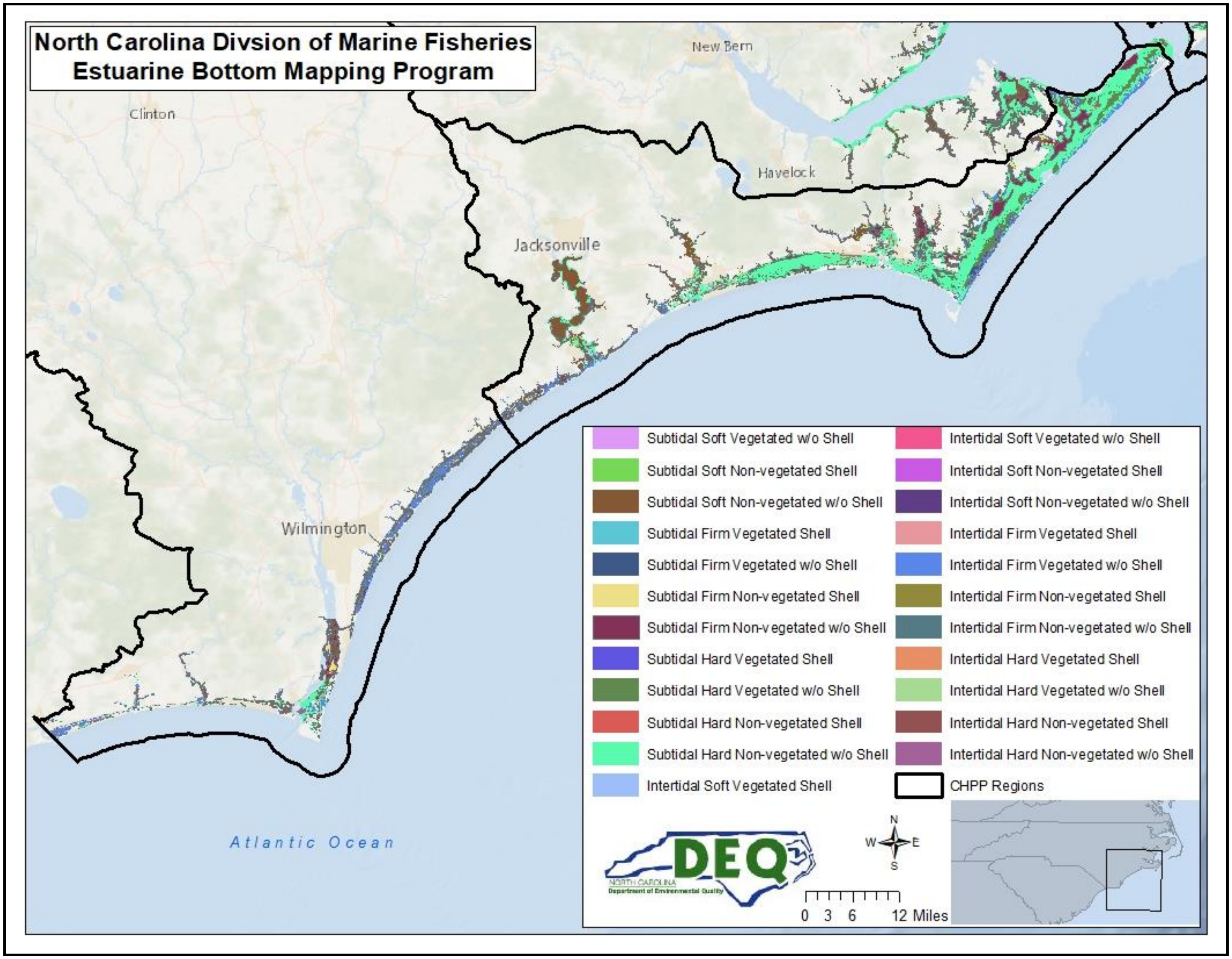

Figure X.30. The North Carolina Division of Marine Fisheries (DMF) Estuarine Bottom Mapping Program (1990-2019) strata for the southern Coastal Habitat Protection Plan (CHPP) regions 3, 3/4, and 4.

After the strata were mapped, sampling was done to quantify the number of eastern oysters, hard clams, and bay scallops present. Since mapping and sampling took place over a long time series, data should be interpreted only as general trends of the density and distribution of shellfish resources across the coast of NC over the last 30 yrs. Comparing shellfish densities across CHPP regions, the White Oak (Region 3) and Cape Fear River (Region 4) river basins had the highest densities for oysters (20.11 oysters/m^2 and 38.95 oysters/m^2, respectively) and clams (0.63 clams/m^2 and 1.21/m^2, respectively) with the White Oak (Region 3) having the highest density for scallops (0.09 scallops/m^2).

The rest of the data presented will focus on eastern oysters since they comprise the majority of shell bottom. To determine the highest density oyster strata coastwide and across CHPP regions, weighted means (oysters/m^2) were examined (Table X.6 and Figure X.31). The Subtidal Soft Vegetated Shell (A) strata does not exist anywhere along the coast due to photosynthetic restraints of vegetation. Across the coast and in every region, Subtidal Firm Non-vegetated Shell (G), Subtidal Hard Non-vegetated Shell (K), Intertidal Firm Non-vegetated Shell (S), and Intertidal Hard Non-vegetated Shell (W) strata were significantly different, with the exception of Intertidal Firm Non-vegetated Shell (S) which did not occur in the Albemarle Sound to Northeastern Coastal Ocean (Region 1; $p<0.05$).

Table X.6. Coastwide and Coastal Habitat Protection Plan (CHPP) region weighted means (oysters/m^2) comparison for eastern oysters by strata from the NC Division of Marine Fisheries (DMF) Estuarine Bottom Mapping Program data.

	Weighted Mean of Oysters (per m^2)				
Strata Description	Coastwide	Region 1	Region 2	Region 3	Region 4
Subtidal Soft Vegetated Shell (A)	-	-	-	-	-
Subtidal Soft Vegetated w/o Shell (B)	0.09	1.40	0.00	0.00	-
Subtidal Soft Non-vegetated Shell (C)	4.75	19.74	3.28	3.21	5.94
Subtidal Soft Non-vegetated w/o Shell (D)	0.08	0.20	<0.01	0.12	0.00
Subtidal Firm Vegetated Shell (E)	7.49	3.45	0.72	12.81	-
Subtidal Firm Vegetated w/o Shell (F)	1.01	0.17	<0.01	1.93	-
Subtidal Firm Non-vegetated Shell (G)	*9.56	*11.26	*6.85	*11.82	*8.05
Subtidal Firm Non-vegetated w/o Shell (H)	0.21	*0.38	0.07	0.22	0.18
Subtidal Hard Vegetated Shell (I)	4.04	12.97	3.33	1.80	-
Subtidal Hard Vegetated w/o Shell (J)	0.05	0.06	0.08	0.04	-
Subtidal Hard Non-vegetated Shell (K)	*16.11	*9.53	*11.60	*19.00	*33.53
Subtidal Hard Non-vegetated w/o Shell (L)	0.04	0.02	0.02	0.02	0.23
Intertidal Soft Vegetated Shell (M)	16.51	-	-	-	23.44
Intertidal Soft Vegetated w/o Shell (N)	4.49	-	-	0.00	4.15
Intertidal Soft Non-vegetated Shell (O)	*41.33	-	-	*55.79	19.50
Intertidal Soft Non-vegetated w/o Shell (P)	0.01	-	-	0.00	0.01
Intertidal Firm Vegetated Shell (Q)	*37.84	3.25	1.53	*34.68	*51.10
Intertidal Firm Vegetated w/o Shell (R)	*2.29	*4.11	0.00	*0.98	*4.69
Intertidal Firm Non-vegetated Shell (S)	*43.23	-	*5.15	*35.74	*46.81
Intertidal Firm Non-vegetated w/o Shell (T)	0.51	0.00	0.00	0.45	0.57
Intertidal Hard Vegetated Shell (U)	*50.23	7.76	4.95	*50.12	*59.41
Intertidal Hard Vegetated w/o Shell (V)	1.29	0.34	<0.01	2.63	0.00
Intertidal Hard Non-vegetated Shell (W)	*91.23	*2.32	*12.89	*101.27	*108.46
Intertidal Hard Non-vegetated w/o Shell (X)	0.01	0.04	<0.01	<0.01	0.00

*significantly different from overall weight mean $p<0.05$

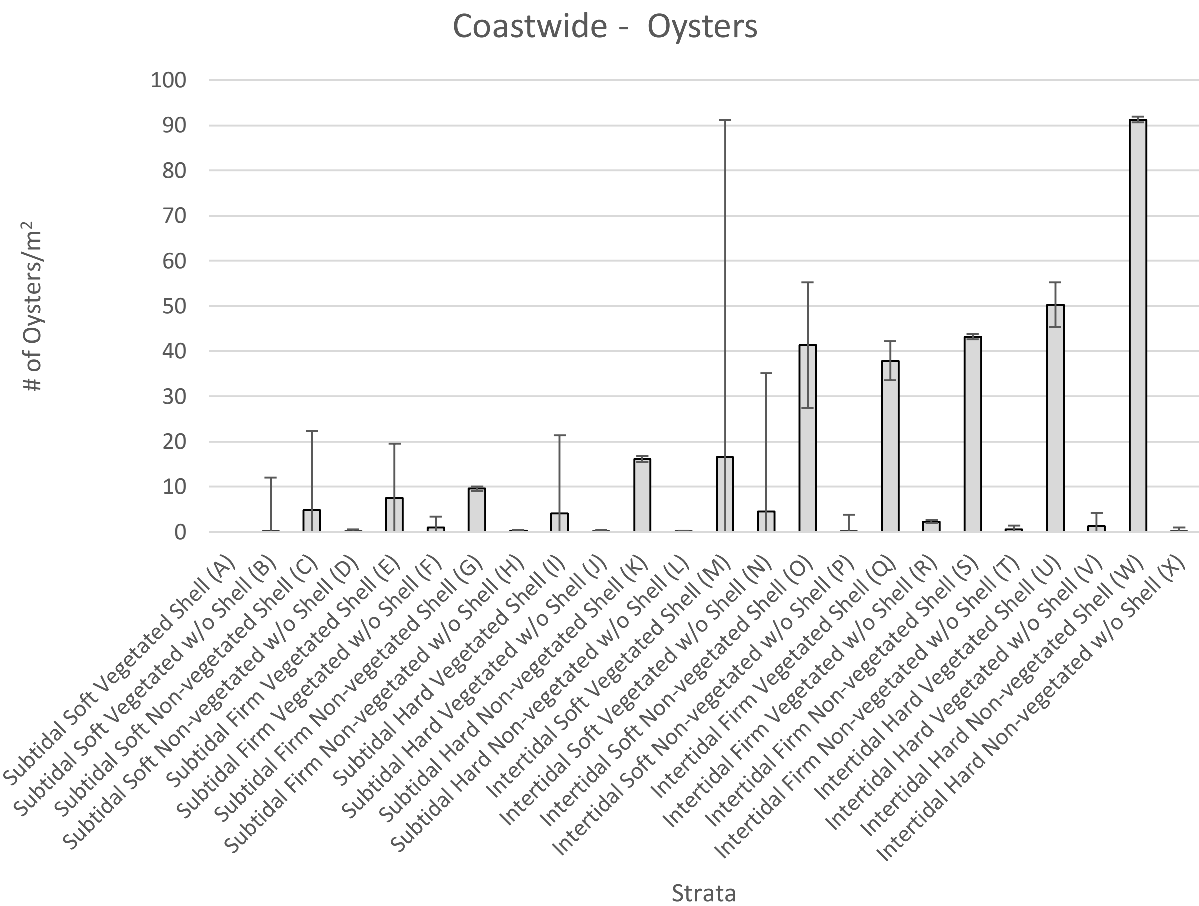

Figure X.31 Coastwide oyster densities (weighted means; # oysters/m^2) by strata from NC Division of Marine Fisheries (DMF) Estuarine Bottom Mapping Program data.

Across the NC coast, the top five highest density strata were: Intertidal Hard Non-vegetated Shell (W; 91.23 ± 0.64 oysters/m^2), Intertidal Hard Vegetated Shell (U; 50.23 ± 4.93 oysters/m^2), Intertidal Firm Non-vegetated Shell (S; 43.23 ± 0.56 oysters/m^2), Intertidal Soft Non-vegetated Shell (O; 41.33 ± 13.88 oysters/m^2), and Intertidal Firm Vegetated Shell (Q; 37.84 ± 4.34 oysters/m^2), and all five strata were significantly different ($p<0.05$; Table X.6 and Figures X.32-X.33). The majority of the oyster resource across the coast, within the mapped study area, were intertidal. Subtidal Firm Non-vegetated Shell (G; 9.56 ± 0.50 oysters/m^2), Subtidal Hard Non-vegetated Shell (K; 16.11 ± 0.68 oysters/m^2), and Intertidal Firm Vegetated w/o Shell (R; 2.29 ± 0.30 oysters/m^2) were also significantly different for oysters coastwide. Two strata, Intertidal Soft Vegetated Shell (M) and Intertidal Soft Vegetated w/o Shell (N), were not significantly different from any other strata for oysters coastwide.

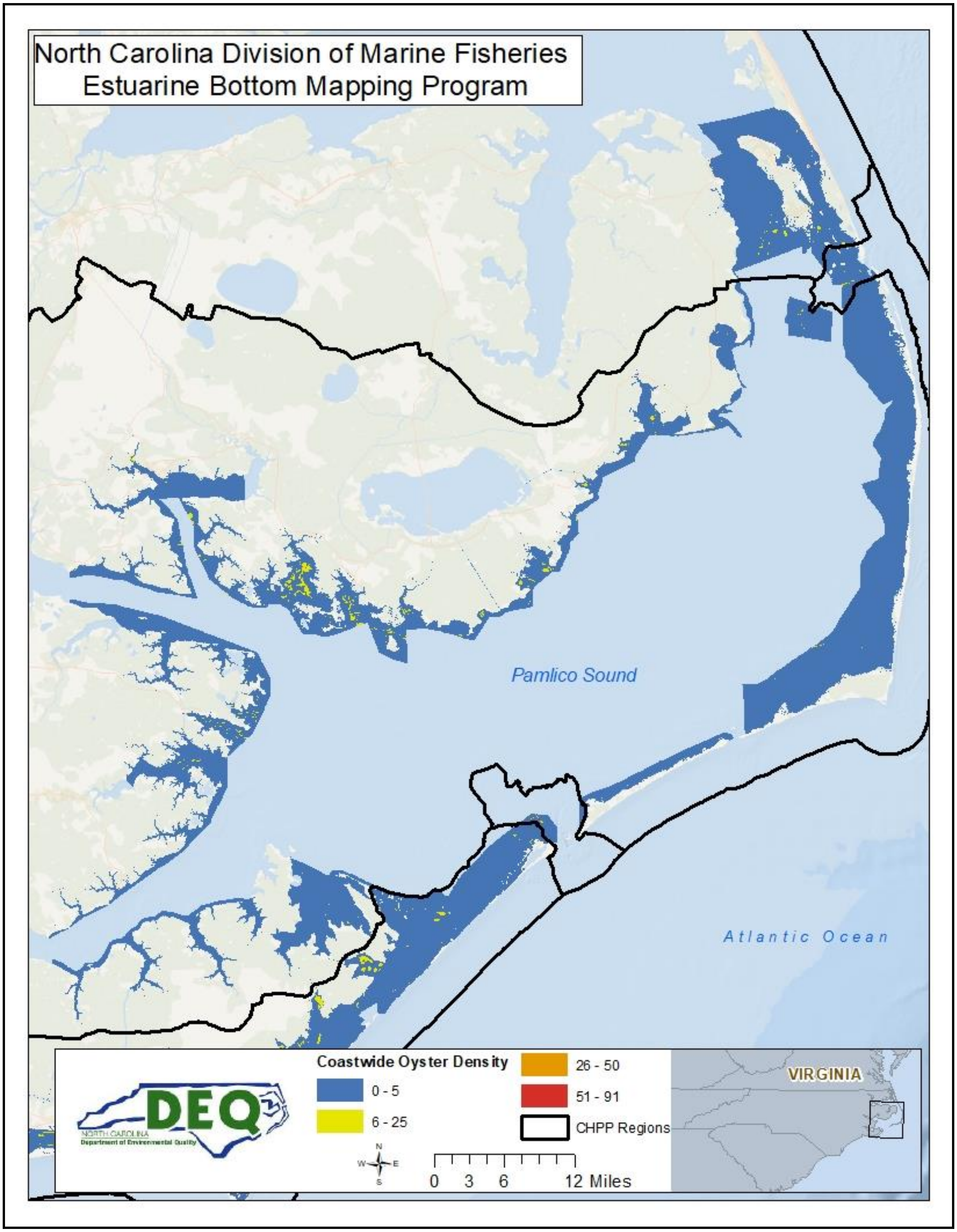

Figure X.32. The North Carolina Division of Marine Fisheries (DMF) Estuarine Bottom Mapping Program (1990-2019) coastwide oyster density (weighted mean; # of oysters/m^2) for the northern Coastal Habitat Protection Plan (CHPP) regions 1, 1/2, and 2.

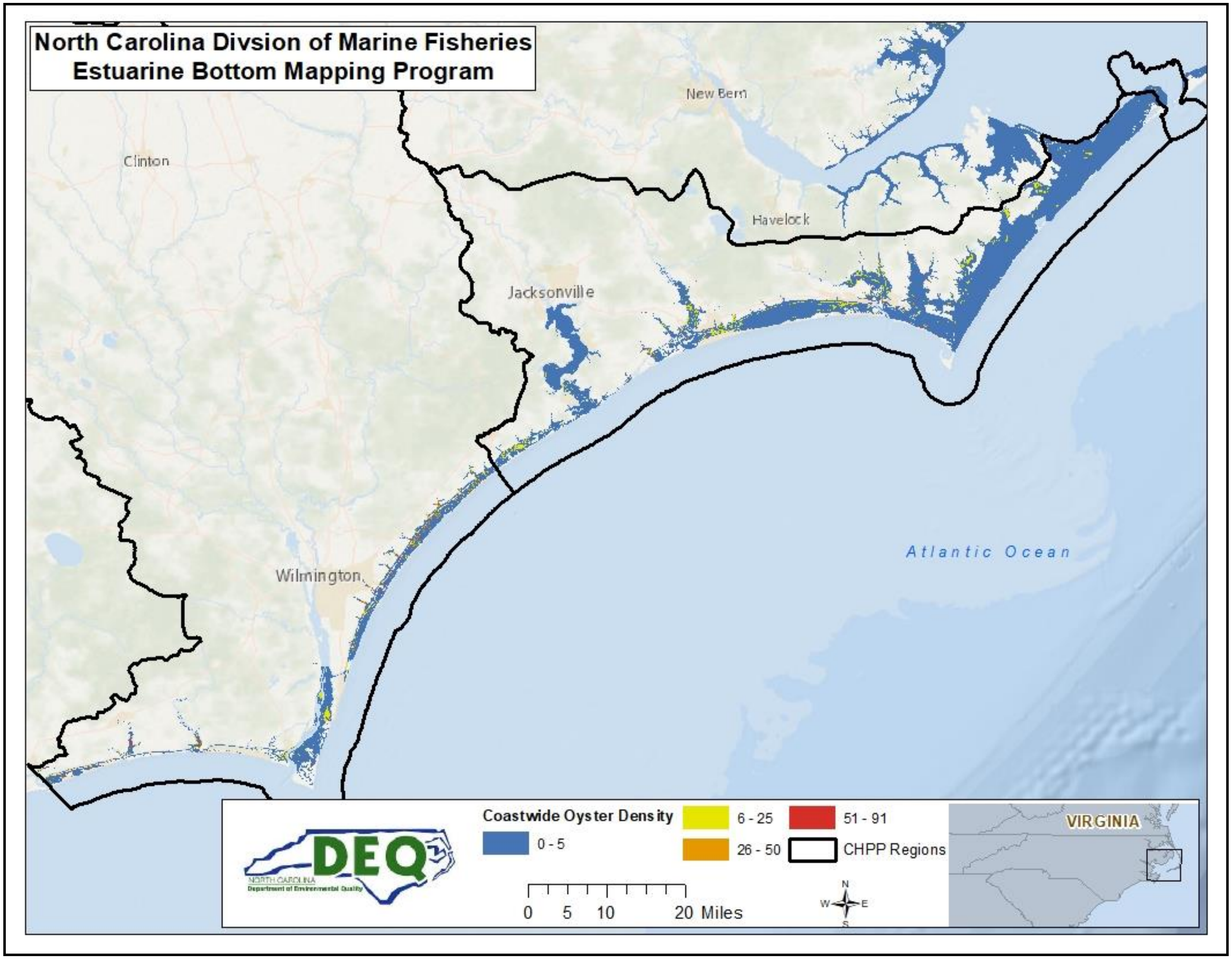

Figure X.33. The North Carolina Division of Marine Fisheries (DMF) Estuarine Bottom Mapping Program (1990-2019) oyster density (weighted mean; # of oyster/m^2) for the southern Coastal Habitat Protection Plan (CHPP) regions 3, 3/4, and 4.

1.4.3. Submerged Aquatic Vegetation (SAV)

Background

Currently, NC is steward to one of the most productive and biodiverse submerged aquatic vegetation (SAV) resources on the Atlantic seaboard, including the largest in-tact polyhaline and mesohaline seagrass meadows in the temperate western Atlantic (Thayer et al. 1984; Carraway and Priddy 1983; Ferguson and Wood 1990, 1994; Green et al. 2003; NCDEQ 2016). There are two distinctive groups of SAV ecosystems in NC distributed according to the estuarine salinity. One group, referred to as low salinity SAV or underwater grasses, thrives in fresh and low salinity riverine waters (≤10 ppt), and includes species such as Redhead grass (*Potamogeton perfoliatus*), Wild celery (*Vallisneria Americana*), and Sago pondweed (*Stuckenia pectinate*). The second group, referred to high salinity SAV or seagrass, occurs in moderate to high (>10 ppt) salinity estuarine waters of the bays, sounds, and tidal creeks, and includes three species, temperate eelgrass (*Zostera marina*), tropical shoal grass (*Halodule wrightii*), and cosmopolitan widgeon grass (*Ruppia maritima*). Collectively, they are referred to as SAV.

When SAV beds are subjected to human-induced impacts, such as physical damage and water quality degradation, in addition to natural stressors, such as storm damage and climate change, large-scale losses may occur. Globally, SAV abundance is declining. Of the 72 known species of seagrass, 10 are at an elevated risk for extinction and three are endangered (Short et al. 2011). Orth et al. (2006) summarized status and trends information of SAV at a global scale and found reports of large-scale SAV losses in the European Mediterranean, Japan, and Australia. Reports of SAV recovery were very low by comparison. Waycott et al. (2009) showed seagrasses disappearing at rates similar to coral reefs and tropical rainforests based on > 215 studies and 1,800 observations dating back to 1879. The compilation of studies shows a 29% decline in known SAV extent since 1879. The study also indicated an acceleration of loss since 1940. In North America, losses of seagrass beds have been as high as 50% in Tampa Bay, 43% in northern Biscayne Bay, 30% in the northern portion of Indian River Lagoon, and as much as 90% in Galveston Bay, Texas, and Chesapeake Bay (Taylor and Saloman 1968; Kemp et al. 1983; Pulich and White 1991; Smith 1998). For more information, see the 2021 CHPP Amendment Issue Paper, Submerged Aquatic Vegetation Habitat Protection and Restoration with Focus on Water Quality.

Mapping and Monitoring

Quantitative information on SAV status and trends comes in three forms: 1) station monitoring, 2) transect monitoring, and 3) areal coverage monitoring. In NC, some of the earliest data comes from a 70+ year history of station and transect monitoring in Currituck Sound (Davis and Brinson 1983, 1990). Studies have documented the status of SAV in Currituck Sound since 1909. Major declines occurred in 1918, which were mostly caused by increased turbidity from dredging for the locks of the Albemarle and Chesapeake Canal. In 1932, operation of the canal locks was modified and SAV began to recover; fully recovering by 1951. During 1954 and 1955, four hurricanes along North Carolina increased turbidities and resulted in widespread destruction of SAV beds (Dickson 1958). The community recovered rapidly, as growth was considered good by 1957 (Davis and Brinson 1983, 1990). After a severe nor'easter in 1962, saltwater intrusion in Currituck Sound raised the average salinity by 4.4 ppt, causing major reductions in freshwater SAV biomass. As SAV beds recovered in Currituck Sound after 1962, non-native Eurasian watermilfoil (*Myriophyllum spicatum*) began to spread across the sound, possibly encouraged by improved water clarity that resulted from dry conditions and higher post-1962 salinities. This caused a major change in composition of the native SAV.

Since the 1980s, various other mapping and monitoring projects have been conducted by universities and state and federal agencies across the coast of NC in both high and low salinity areas. The data sources, mapping years, methodology, and extent of each individual mapping event is described in Table

X.X. Each of these mapping events produced individual GIS files, that when compiled together, make up the historically known presence and suitable habitat of SAV along NC's coast, suggesting a historic extent of approximately 191,155 acres of SAV in the public trust waters of coastal NC (Table X.7 and Figures X.33-X.X). Additional mapping and monitoring of fresh and brackish SAV has occurred with hydroacoustic surveys, the recent establishment of sentinel sites in recent years in the Neuse and Pamlico rivers and Albemarle Sound (Luczkovich and Zenil 2015; Luczkovich 2016, 2018; Zenil 2020) and a coastwide aerial photography mapping event that occurred in 2019 and 2020 with funding from DEQ and APNEP. As these more current data layers become available they will be incorporated into this mosaic of NC SAV mapping events to better inform the known historic and current extent of SAV in NC.

Table X.7. The data sources, mapping years, methodology, and extent of each individual SAV mapping events along the North Carolina Coast from 1981 to 2015.

Data Source	**Mapping Year(s)**	**Methodology**	**Mapping Extent**
Carraway & Priddy (1983)	1981	Maps of SAV were created from aerial natural color photography accompanied by ground truth data for verification including location and density. Link to report	May 1981: Bogue and Core sounds
Ferguson & Wood (1994)	1983, 1985, 1988, 1990, 1992	SAV was delineated and mapped from natural color aerial photography with a minimum mapping unit of 20m. Accompanying field inventories were conducted within study regions to verify SRV signatures and species distribution and composition. Link to report	1990: Currituck, Albemarle and Roanoke/Croatan 1991: Pamlico River Estuary, Neuse River Estuary, western Pamlico Sound and Albemarle 1992: Pamlico River, Core and Bogue and parts of eastern Pamlico Sound, western Pamlico Sound, Albemarle (Perquimans River)
Division Water Quality (DWQ) 1998	1998	Maps from aerial photography	Neuse River and tributaries
Eastern Carolina University (ECU)	2002-2003, 2006	Maps from aerial photography	Albemarle and Currituck sounds
North Carolina State University (NCSU)	2005	Aerial photography from July 2005 accompanied by ground truth data Link to project summary	Southern shore of Albemarle Sound including Bull Bay to northern Croatan Sound
Division Water Quality Rapid Response Team	2005-2008	Maps from interpolated transect data. SAV was observed and collected using a garden rake from boat, traveling along the shoreline. Link to 2005 Report and2007 Report	2005 & 2006 (June-September): major tributaries of Neuse and Pamlico Rivers 2007 (May-August): Neuse and Pamlico Rivers and tributaries
Marine Corps Air Station Cherry Point	2007	Field survey's consisting of visual observations and underwater cameras and aerial survey analysis of hyperspectral imagery. Link to report	Mouth of the Neuse River near Point of Marsh.
Albemarle Pamlico National Estuarine Partnership (SAV Partners)	2006-2008	SAV was mapped along the coast of NC and northward into Back Bay, Virginia by manually digitizing visible SAV from remotely-sensed imagery. Link to metadata	This extent encompasses the coastal zone that lies within the APNEP regional boundary (Bogue Inlet north to Back Bay), as well as that which is outside of that boundary (Bogue Inlet south to Masonboro Inlet).
	2012-2014	SAV was mapped along the coast of NC by manually digitizing visible SAV from remotely-sensed imagery. Link to metadata	This extent encompasses the high-salinity coastal zone that lies within the APNEP regional boundary (Hwy. 64 Bridge of Roanoke Sound south to Bogue Inlet).
DEQ, DOT, & NOAA	2015	SAV was mapped along the Southern coast of NC by manually digitizing visible SAV from remotely-sensed imagery. Link to metadata	This extent encompasses the high-salinity coastal zone of Onslow Bay that lies south of the APNEP regional boundary.

Table X.8. Historical extent of submerged aquatic vegetation (SAV) in North Carolina (SAV Mosaic 1981 to 2015 (Figures X.33-X.41).

Salinity Zone	SAV Region #	SAV Region Name	Historic Extent* (ac)	Percent of Historical Extent* (%)
Low	1	Currituck and Back Bay	21,613	11.3
Low	2	Albemarle Sound	12,872	6.7
Low	3	Tar-Pamlico & Neuse rivers	4,581	2.4
High	4	Pamlico Sound	712	0.4
High	5	Roanoke Sound to Ocracoke Inlet	101,739	53.2
High	6	Core Sound	36,862	19.3
High	7	Bogue Sound	10,826	5.7
High	8	Bear Inlet to Snow's Cut	1,950	1.0
High/Low	9	Cape Fear River to SC line	0	0.0
Total			**191,155**	100.0

*SAV Mosaic 1981 to 2015 (as of 6/3/2020)

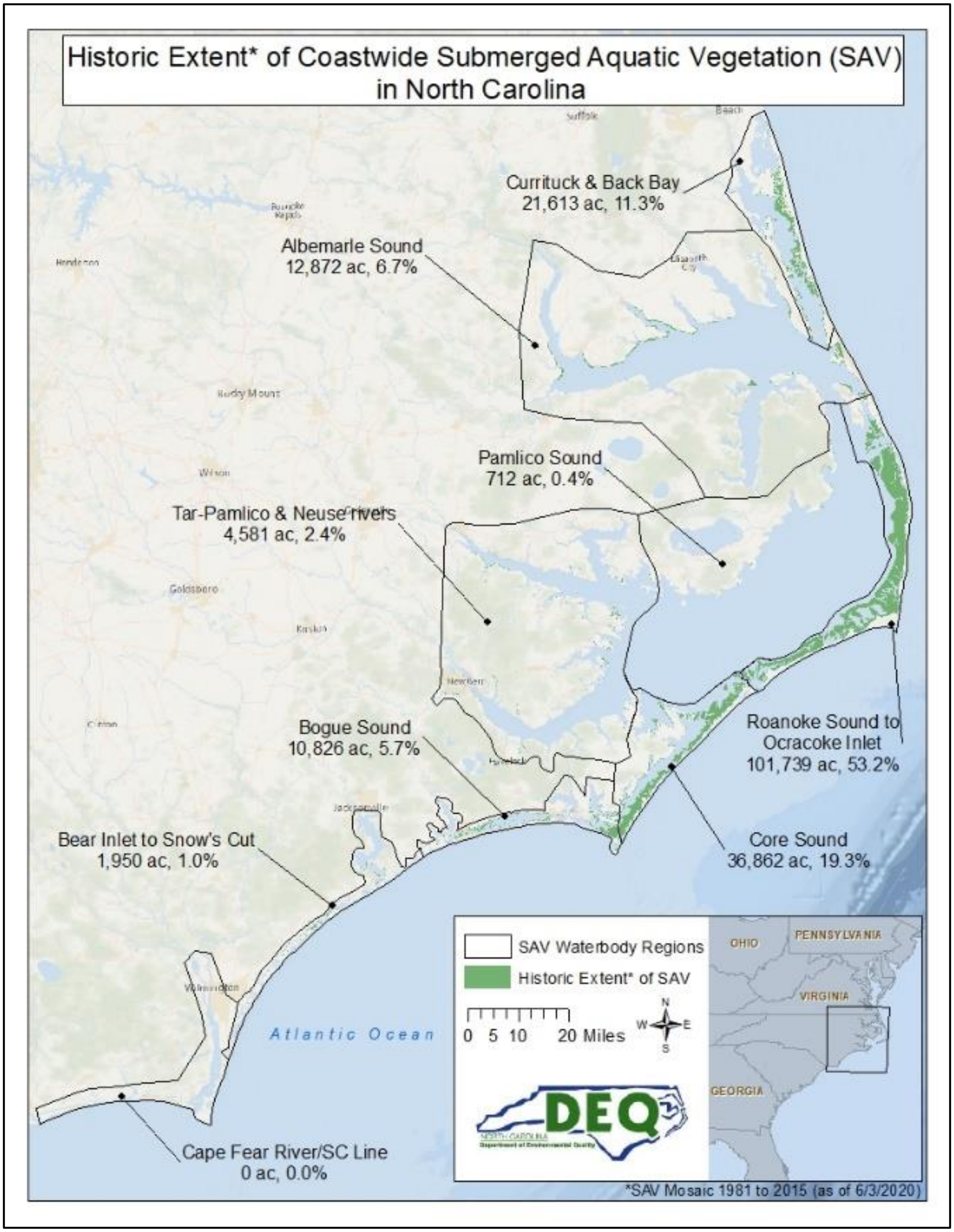

Figure X.33. Known historic extent of SAV in North Carolina, mapped from 1981 to 2015. Absence of SAV does not suggest actual absence, as surveys have not been conducted in all areas. Presence of SAV does not reflect current state, as data dates to 1981.

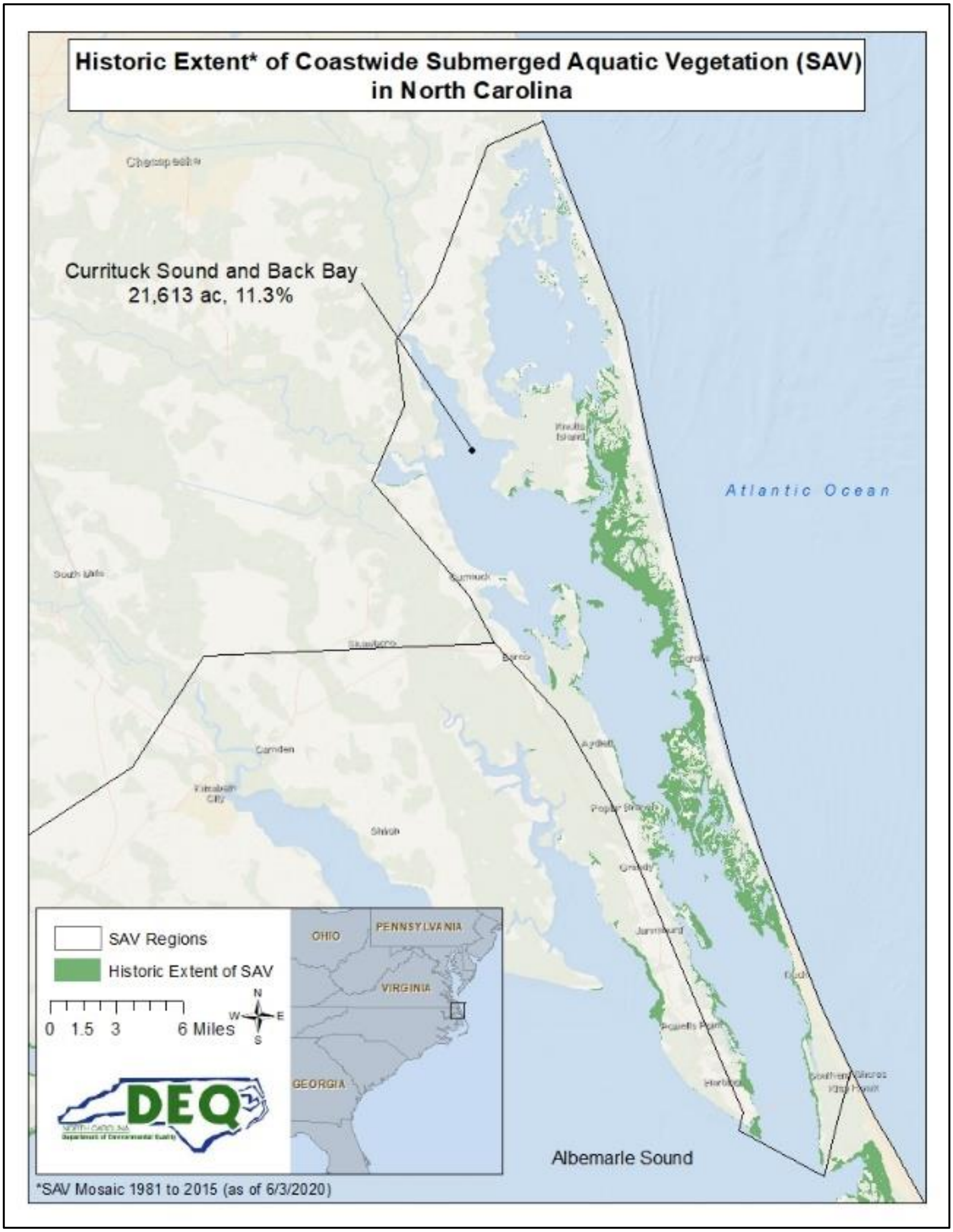

Figure X.34. Known historic extent of SAV in NC, mapped from 1981 to 2015 in Currituck and Back Bay. Absence of SAV does not suggest actual absence, as surveys have not been conducted in all areas. Presence of SAV does not reflect current state, as data dates to 1981.

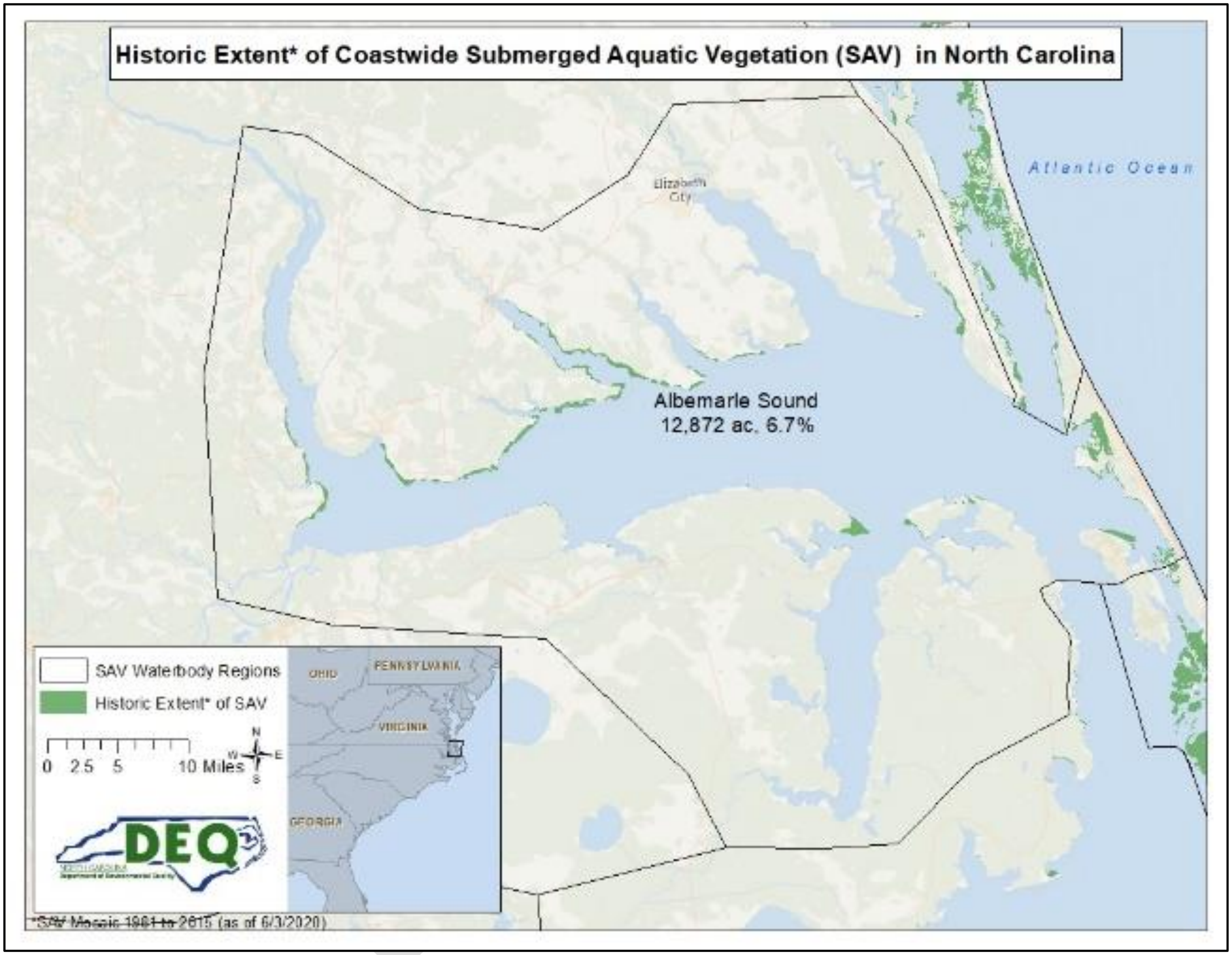

Figure X.35. Known historic extent of SAV in NC, mapped from 1981 to 2015 in Albemarle Sound. Absence of SAV does not suggest actual absence, as surveys have not been conducted in all areas. Presence of SAV does not reflect current state, as data dates to 1981.

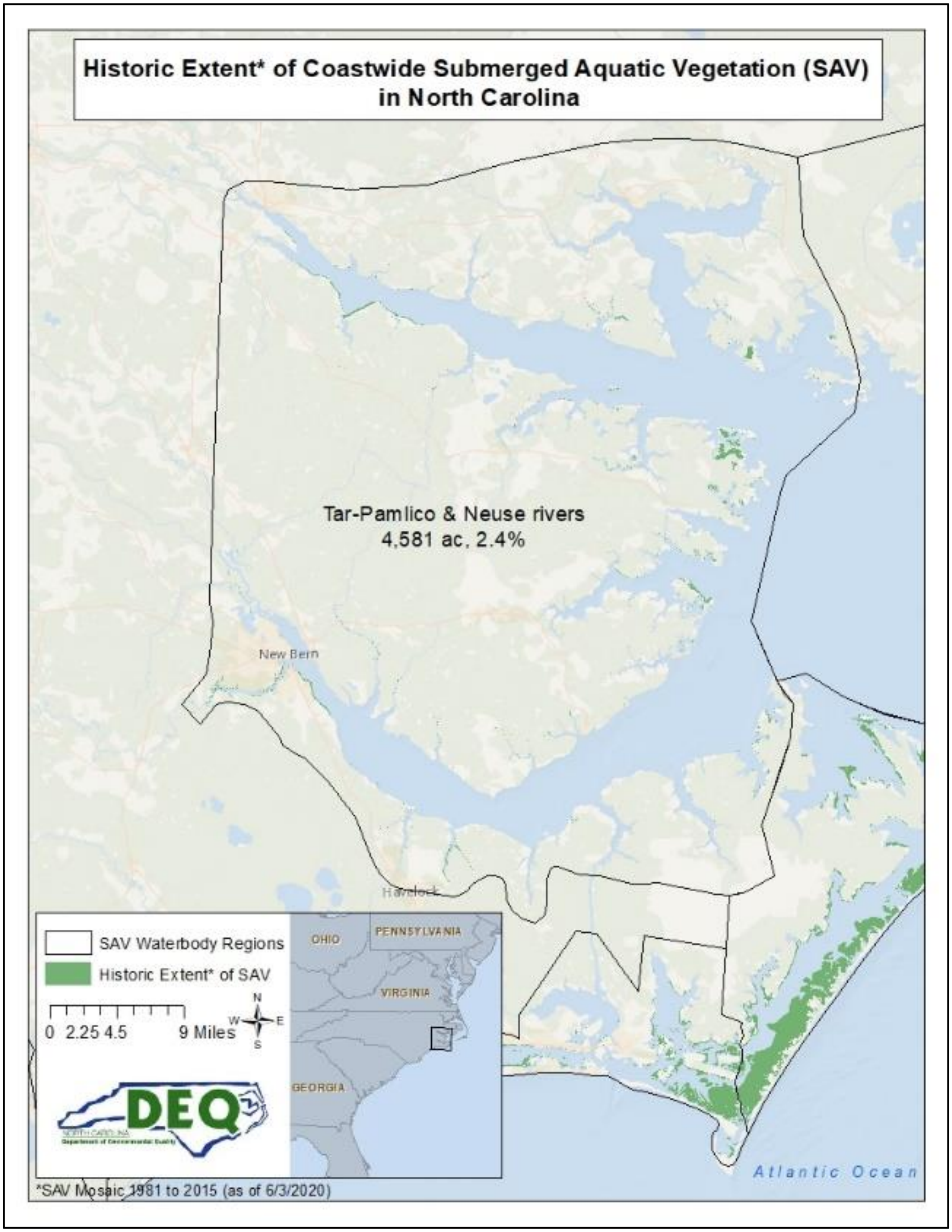

Figure X.36. Known historic extent of SAV in NC, mapped from 1981 to 2015 in Tar-Pamlico and Neuse rivers. Absence of SAV does not suggest actual absence, as surveys have not been conducted in all areas. Presence of SAV does not reflect current state, as data dates to 1981.

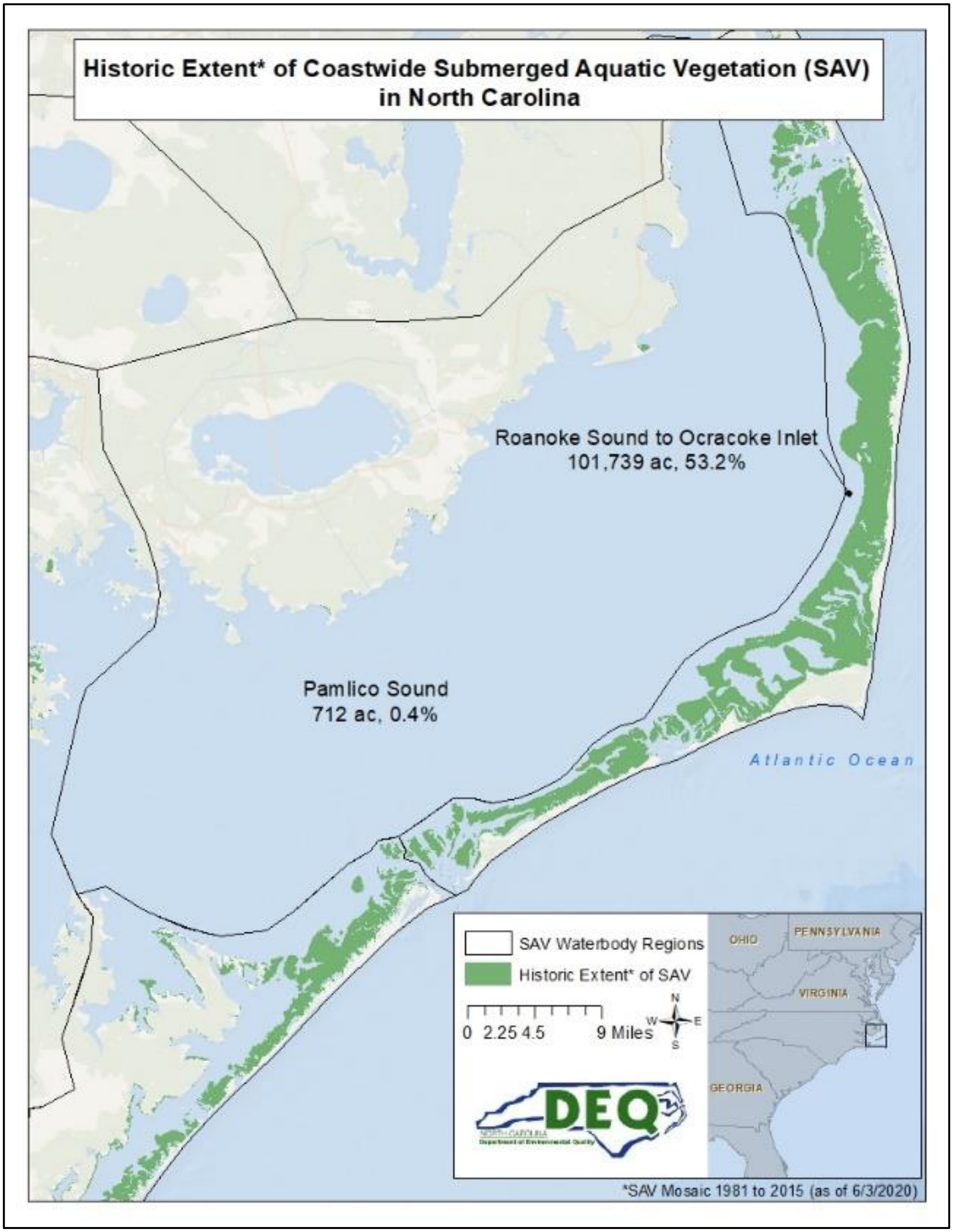

Figure X.37. Known historic extent of SAV in NC, mapped from 1981 to 2015 in Pamlico Sound. Absence of SAV does not suggest actual absence, as surveys have not been conducted in all areas. Presence of SAV does not reflect current state, as data dates to 1981.

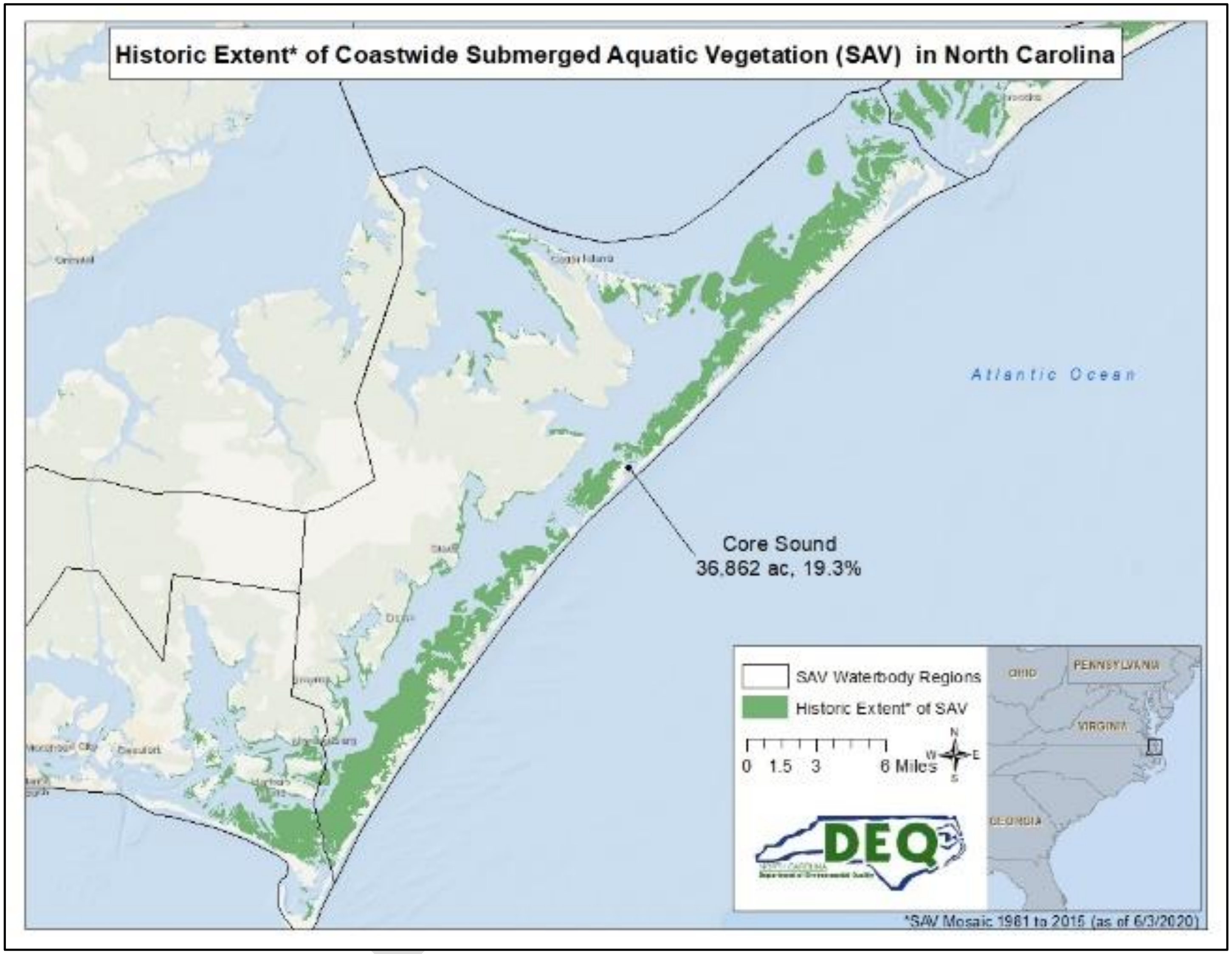

Figure X.38. Known historic extent of SAV in NC, mapped from 1981 to 2015 in Core Sound. Absence of SAV does not suggest actual absence, as surveys have not been conducted in all areas. Presence of SAV does not reflect current state, as data dates to 1981.

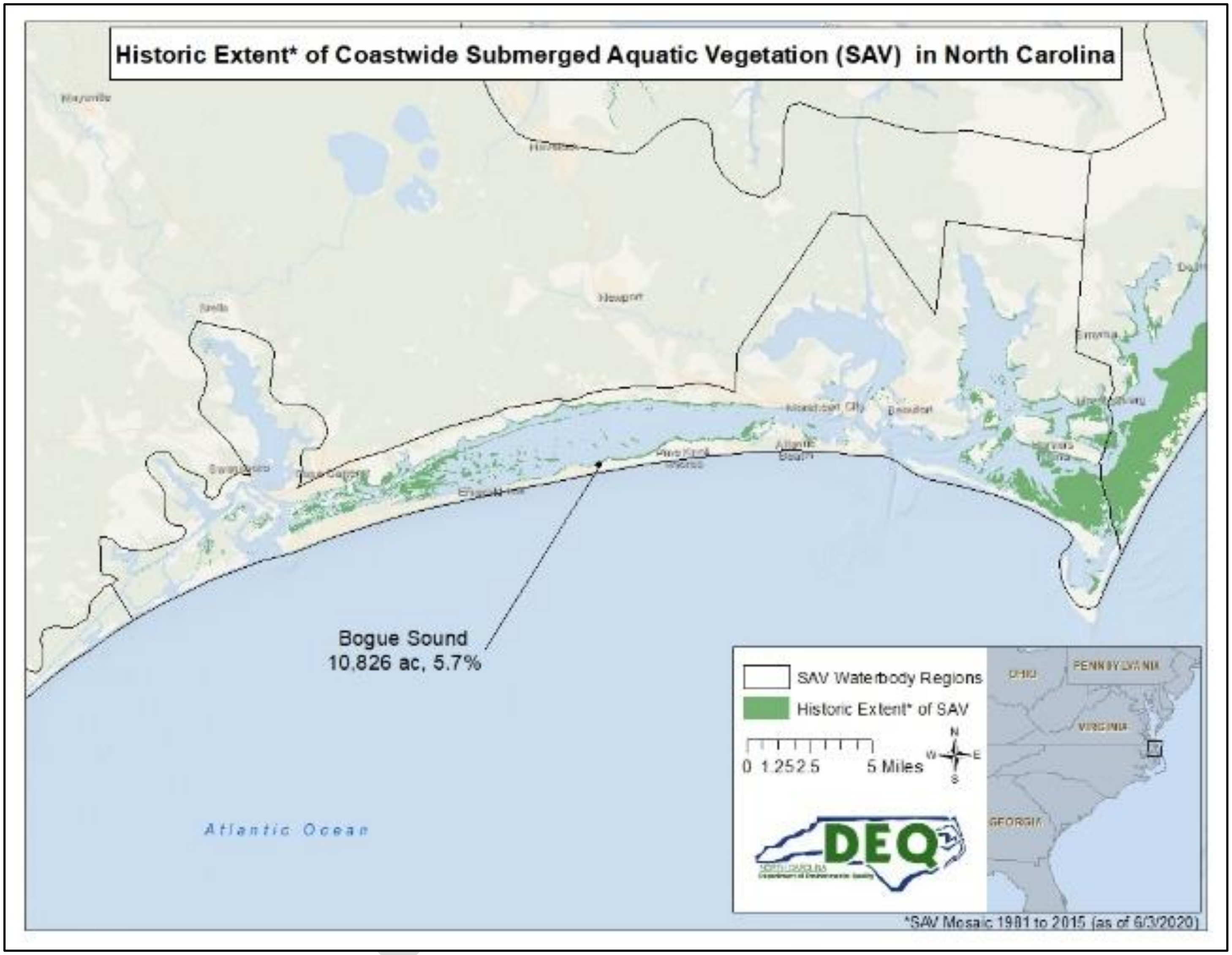

Figure X.39. Known historic extent of SAV in NC, mapped from 1981 to 2015 in Bogue Sound. Absence of SAV does not suggest actual absence, as surveys have not been conducted in all areas. Presence of SAV does not reflect current state, as data dates to 1981.

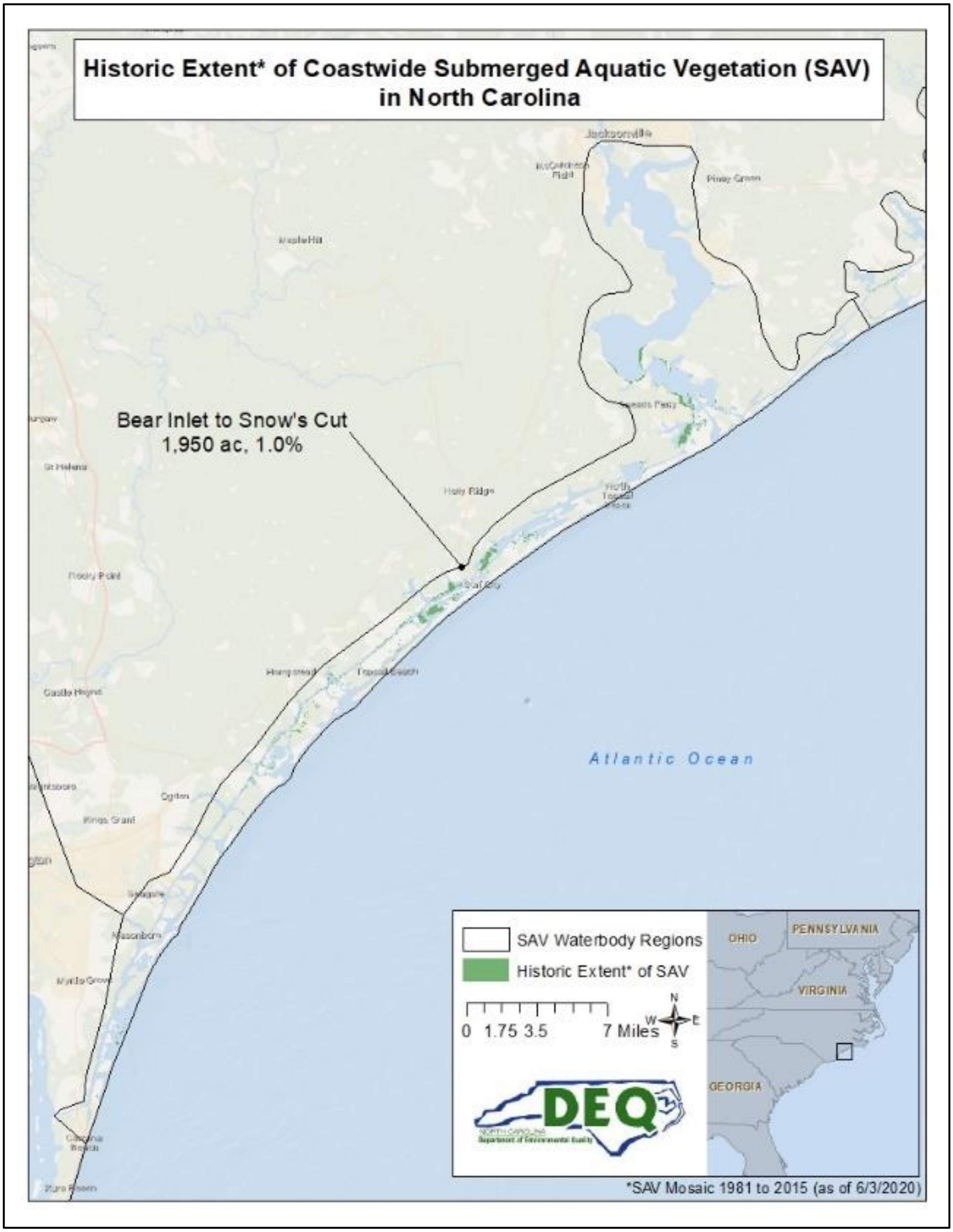

Figure X.40. Known historic extent of SAV in NC, mapped from 1981 to 2015 in Bear Inlet to Snows Cut. Absence of SAV does not suggest actual absence, as surveys have not been conducted in all areas. Presence of SAV does not reflect current state, as data dates to 1981.

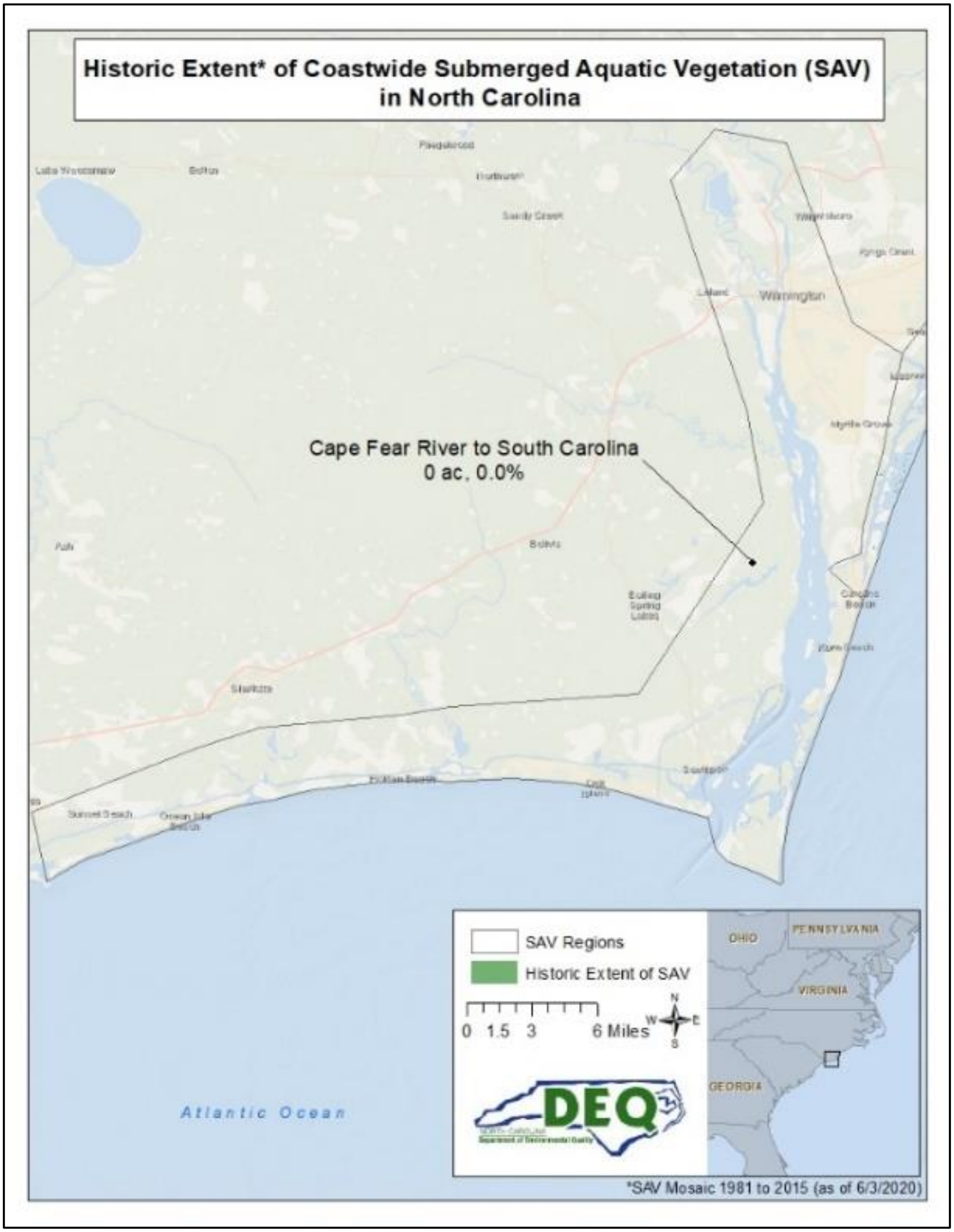

Figure X.41. Known historic extent of SAV in NC, mapped from 1981 to 2015 in Cape Fear River to the South Carolina line. Absence of SAV does not suggest actual absence, as surveys have not been conducted in all areas. Presence of SAV does not reflect current state, as data dates to 1981.

Extent and Loss in North Carolina

The extent of SAV loss has not been well quantified in North Carolina, but anecdotal reports indicate SAV beds may be reduced by as much as 50 percent, especially on the mainland side of the coastal sounds (Seagrant 1997; Moorman et al. 2014; NCDEQ 2016). However, more recent efforts have been made to quantify these losses in both high and low salinity SAV habitats (APNEP 2020; Speight 2020). Mapping and monitoring low salinity SAV is more difficult due to low water clarity compared to high salinity SAV areas of the estuary. However, despite the limited availability of historical baseline data of low salinity SAV habitat, fluctuations in SAV abundance have been observed through hydroacoustic surveys and other sentinel site observations. Based on the most recent hydroacoustic surveys of linear SAV extent along the 1-m isobath in the Neuse, Pamlico and Albemarle river sub-estuaries, there has been an estimated 33% decline from the historical extent of low salinity SAVs (Table X.8) (APNEP 2020; Speight 2020).

Table X.8. Net change from known historic extent to 2014-2017 linear extent (LE) data along 1-meter isobaths line for low salinity SAV based on hydroacoustic surveys (Source: APNEP 2020; Speight 2020).

Estuary	Known Historical* SAV LE (m)	2014-2017 SAV LE (m)	No change in SAV from historical (m)	Change in SAV LE (gain)	Change in SAV LE (loss)	Percent change in SAV LE (loss)
Albemarle Sound	117,778	90,565	56,457	+34,108	-61,321	-23.10
Tar - Pamlico River	29,223	6,036	756	+5,280	-28,467	-79.33
Neuse River	10,512	9,519	2,821	+6,692	-7,685	-9.42
Total	157,513	106,120	60,034	+46,080	-97,473	-32.62

*From 1981-2015 SAV Mosaic

Although there is less known about low salinity SAV, there are some recurring themes. These include fluctuations in abundance, changes in species composition, a proliferation of non-native, persistent SAV species, high turbidity, extreme weather events and large amounts of precipitation, increases in harmful algal blooms, and fluctuations in salinity. This all represents an important and needed effort to develop numeric nutrient criteria, so that progress on water quality improvements can be made for the benefits of SAV (APNEP 2020). The high salinity seagrasses appear to be in slightly better health than the low salinity SAVs. There is a good baseline of data on distribution and abundance for most of the high salinity SAV resource, along with a good understanding of species composition, persistence, and resilience. However, little water quality data are collected in this part of the estuary and represents a crucial data gap.

The APNEP metric report: Extent of Submerged Aquatic Vegetation, High-Salinity Estuarine Waters, provides an analysis of SAV change based on spatial coverage detected from aircraft during two survey periods: 2006-2007 (Survey 1) and 2013 (Survey 2). Survey 1 represents late spring aerial surveys of Bogue and Back Sounds and fall aerial surveys between Roanoke Island and Barden's Inlet. Survey 2 represents late spring aerial surveys between Roanoke Island and Bogue Inlet (Field et al. 2020). Due to weather conditions during the second survey, extent and location measurements for SAV in much of Core Sound was not included in this report. For the analysis, the coastal areas were broken down into three geographic regions: 1) the "North Zone" from the U.S. Highway 64 Bridge at Roanoke Island to Hatteras Inlet, 2) the "Central Zone" from Hatteras Inlet to Ophelia Inlet and, 3) the "South Zone" from Barden's Inlet at Cape Lookout to Bogue Inlet. The data were also subdivided into the categories showing all possible categorical changes in SAV: continuous to none, patchy to none, continuous to patchy, patchy both years of analysis, none to patchy, continuous both years of analysis, patchy to continuous, and none to continuous.

All three regional zones showed declines in SAV acreage (Table X.9). However, the southern zone, where there is more development and higher population densities, declined by over 10% at a rate of 1.7% loss per year (Field et al. 2020; Table X.10). The northern and central regions are less developed, receive less direct riverine input, and therefore had a lower estimated SAV acreage loss. SAV can grow at depths generally up to ≤ 2.0 m, yet much of the available benthic habitat within this depth range was not occupied by SAV. An additional concern is the amount of continuous beds that were converted to patchy beds. The biggest component of the overall change in the northern region was the conversion of 15,327 acres (6,202.8 ha) of continuous seagrass in Survey 1 to patchy seagrass in Survey 2.

Table X.9. Net change in seagrass extent in North Carolina from Survey 1 (2006/2007) to Survey 2 (2013) in three regional zones 1) the “North Zone” from the U.S. Highway 64 Bridge at Roanoke Island to Hatteras Inlet, 2) the “Central Zone” from Hatteras Inlet to Ophelia Inlet and, 3) the “South Zone” from Barden’s Inlet at Cape Lookout to Bogue Inlet and overall (acres, hectares in parentheses). (Source: Field et al. 2020).

Regional Zones	Survey 1	Survey 2	Change	% Change
North	70,861 (28,676)	66,445 (26,889)	-4,416 (-1,787)	-6.2
Central	24,132 (9,766)	23,477 (9,501)	-655 (-265)	-2.7
South	5,850 (2,367)	5,235 (2,119)	-615 (-249)	-10.5
Overall	100,843 (40,810)	95,157 (38,509)	-5,686 (-2,301)	-5.6

Table X.10. From-to calculations for the net change in seagrass extent in the three North Carolina zones 1) the “North Zone” from the U.S. Highway 64 Bridge at Roanoke Island to Hatteras Inlet, 2) the “Central Zone” from Hatteras Inlet to Ophelia Inlet and, 3) the “South Zone” from Barden’s Inlet at Cape Lookout to Bogue Inlet and overall (acres, hectares in parentheses). (Source: Field et al. 2020).

Conversion		**Zone**		
From	To	North	Central	South
No SAV	Patchy SAV	4,462 (1,810)	4,386 (1,775)	638 (258)
No SAV	Continuous SAV	203 (82)	150 (601)	60 (24)
	Gain	4,665 (1,888)	4,537 (1,836)	698 (283)
Continuous	None	1,895 (766)	401 (162)	88.4 (36)
Patchy	None	7,009 (2,837)	4,782 (1,935)	1,218 (493)
	Loss	8,904 (3,603)	5,184 (2,098)	1,306 (528)
Net Loss (Loss – Gain)		4,239 (1,715)	647 (262)	607 (246)
Total		70,861 (28,676)	24,132 (9,766)	5,850 (2,367)
% Change		-6.2	-2.7	-10.5
% Change yr-1		-1.1	-0.5	-1.7

Waycott et al. (2009) performed a global assessment of 215 studies and found that seagrasses around the world have been disappearing at a rate of 110 km^2 per year since 1980 with an overall global average rate of decline of 1.5% per year. Although rates of decline within the northern and central regions of NC are lower than this global average, the higher rate of decline in Back and Bogue sounds (1.7% per year) is comparable (APNEP 2020; Field et al. 2020). Bogue and Back Sounds may be especially vulnerable to the impairment of water quality associated with shoreline development and other anthropomorphic impacts (boat wakes, dredging, fishing gears, etc.).

1.4.4. Wetlands

There are multiple classification systems used to differentiate classes of wetlands, but for the purposes of this paper, we will be using a simplified Cowardin System which splits coastal wetlands into two broad classes: palustrine and estuarine. Palustrine wetlands include all non-tidal wetlands that are dominated by trees, shrubs, or emergent vegetation, as well as any tidal wetlands where ocean-derived salinities are less than 0.5 parts per thousand (ppt). Wetlands with ocean-derived salinities greater than 0.5 ppt are categorized as estuarine wetlands, which can be further divided by vegetation type into forested, scrub/shrub, and emergent estuarine wetlands.

Wetland resources in the United States have declined considerably (>50%) since the colonial period (Davidson 2014). It is estimated nearly half of North Carolina's 11 million historical acres of wetlands were lost (physically or functional) between pre-colonial times and the 1980s (Stedman and Dahl 2008). These alterations were not evenly distributed between wetland types, with 52.4% of coastal palustrine wetlands having been altered, in contrast with 12.2% of estuarine wetlands (Cashin et al. 1992). The loss of North Carolina's coastal wetlands has continued into the 21st century.

<u>Extent in North Carolina</u>

Approximately 95% of North Carolina's wetland resources are in the state's Coastal Plain (USFWS 2020). According to the most recent NOAA Coastal Change Analysis Program (C-CAP) data, North Carolina has 4.35 million acres of palustrine (freshwater) wetlands, of which 71% are forested wetlands, 23% are scrub/shrub wetlands, and 6% are emergent wetlands, as well as 235,425 acres of estuarine wetlands, of which 97% are emergent wetlands (NOAA C-CAP 2020; Table X.11).It is estimated nearly half of NC's 11 million historical acres of wetlands were lost between pre-colonial times and the 1980s (Stedman and Dahl 2008). The percent of wetlands impacted to the point of no longer supporting their original function exceeded 50% by the 1980s (Cashin et al. 1992). These alterations were not evenly distributed between wetland types, with 52.4% of coastal palustrine wetlands having been altered by the 1980s, in contrast with 12.2% of estuarine wetlands. Unfortunately, wetland loss is not a relic of North Carolina's past. Approximately 40% of total documented coastal wetland losses occurred between 1950 and 2000 (Cashin et al. 1992).

Table X.11. Acres of palustrine (freshwater) and estuarine wetlands in North Carolina's Coastal Plain. Data Source: NOAA Coastal Change Analysis Program (C-CAP) 2016.

Coastal Wetland Class	Acres
Palustrine Forested Wetland	3,069,690
Palustrine Scrub/Shrub Wetland	1,008,552
Palustrine Emergent Wetland	272,932
Estuarine Forested Wetland	166
Estuarine Scrub/Shrub Wetland	7,747
Estuarine Emergent Marsh	235,425
Total	4,594,513

The loss of NC's coastal wetlands has continued into the 21st century. Calculating wetland change over five year periods beginning in 1996, the recent C-CAP publication of 2011-2016 data provides 20 years of wetland change data for NC's Coastal Plain. Documented within the 20 year period from 1996-2016, 135,000 acres of palustrine wetland were lost in NC's coastal plain (NOTable X.12). Roughly 72% of all coastal freshwater wetland losses documented occurred in the first five-year period from 1996 to 2001. A net loss of coastal freshwater wetland was observed 1996 to 2011, with the conversion of freshwater wetlands to upland habitat accounting for the majority of losses (54%-80%). From 1996 to 2011, the rate of net coastal freshwater wetland loss decreased with 2011 to 2016 reporting a net increase. The conversion from upland habitat resulted in a net gain in freshwater wetlands, while conversion to development accounted for 90% of all observed palustrine wetland losses.

Table X.12. Net loss or gain of North Carolina's coastal palustrine wetland acreage to other land cover classes, by conversion type. Negative values represent a loss of coastal palustrine wetlands to the specified land cover class and positive values represent a gain. Net change represents net change from all land conversions during that time period. Data Source: NOAA Coastal Change Analysis Program (C-CAP) 2016.

	Conversion Between Palustrine Wetlands and:						
Time Period	Development	Agriculture	Upland	Estuarine Wetlands	Unconsolidated Shore	Open Water	Net Change
2011-2016	-1,317	0	637	0	-144	3,952	3,128
2006-2011	-3,001	127	-9,748	0	-39	-3,973	-16,633
2001-2006	-2,172	-2,476	-13,493	0	16	-6,840	-24,965
1996-2001	-6,450	-9,218	-77,636	0	46	-3,255	-96,513
20-Yr Total	-12,940	-11,567	-100,240	0	-121	-10,116	-134,983

While the magnitude of cumulative losses to coastal palustrine wetlands from 1996 to 2011, the proportion of loss was not evenly distributed among palustrine subclasses. Palustrine forested wetlands, which account for 71% of all coastal palustrine wetland acreage, accounted for 99% of overall net losses incurred across all three classes over the 20-years of NOAA C-CAP data (Table X.13).

Table X.13. Net loss or gain of North Carolina's coastal palustrine (freshwater) wetland acreage by type palustrine wetland classes. Negative values represent a net loss of coastal palustrine wetlands and positive values represent a net gain of coastal palustrine wetlands. Data Source: NOAA Coastal Change Analysis Program (C-CAP).

Time Period	Palustrine Forested Wetland	Palustrine Scrub/Shrub Wetland	Palustrine Emergent Wetland
2011-2016	-42,969	40,277	5,816
2006-2011	-115,836	99,574	-265
2001-2006	-150,287	89,661	35,664
1996-2001	-279,324	147,607	35,204
20-yr Total	-588,416	377,119	76,419

These losses, totaling 588,523 acres of forested palustrine wetlands between 1996 and 2016, were offset by gains of 377,119 acres and 76,684 acres of coastal palustrine scrub/shrub and emergent wetlands, respectively, over the same period. Between 1996 and2016, conversion to palustrine scrub/shrub wetland accounted for 42% of cumulative palustrine forested wetlands losses, conversion to palustrine emergent wetland accounted for 37% of cumulative losses, and conversion to upland accounted for 16% of losses (Table X.14). Palustrine scrub/shrub wetlands were the only palustrine wetland class in which net gains in acreage were observed across all four five-year periods between 1996 and 2016. Of 381,426 acres of palustrine scrub/shrub wetland gained between 1996 and 2016, conversion from palustrine forested wetland accounted for 64% of gains and palustrine emergent wetland accounted for 35%. Conversion of palustrine scrub/shrub to development, which totaled 1,592 acres over the 20-year period, accounted for the largest percentage (42%) of cumulative losses. Conversion from palustrine forested wetland was also the major contributor (>99%) to palustrine emergent wetland acreage gains between 1996 and 2016. Of the 219,520 acres of palustrine emergent wetland gained through conversion of palustrine forested wetland, the leading contributor to palustrine emergent wetland losses, conversion to palustrine scrub/shrub wetland, negated 62% of those potential gains. Indeed, recent analysis of palustrine wetland losses in coastal counties of the conterminous U.S. found that 80% of palustrine wetland losses occurring between 1996 and 2010 occurred in five states, with NC ranking fifth and accounting for 8% of all losses incurred nationally over the period (Gittman et al. 2019).

Table X.14. Net loss or gain of North Carolina's coastal palustrine forested, scrub/shrub, and emergent wetland acreage by type of conversion to other land cover classes. Negative values represent a net loss of the coastal palustrine wetland class and positive values represent a net gain of the coastal palustrine wetland class. Data Source: NOAA Coastal Change Analysis Program (C-CAP).

	Time Period			
	2011-2016	2006-2011	2001-2006	1996-2001
Palustrine Forested Wetland Conversion To:				
Development	-870	-1,530	-1,281	-6,027
Agriculture	0	227	-1,783	-7,784
Upland	367	-7,755	-10,993	-77,143
Palustrine Scrub/Shrub Wetland	-10,816	-57,626	-54,957	-122,149
Palustrine Emergent Wetland	-34,308	-45,049	-77,125	-63,038
Estuarine	0	0	0	0
Unconsolidated Shore	-66	-2	-2	11
Open Water	2,724	-4,206	-4,149	-3,193
Net Over Change	-42,969	-115,941	-150,290	-279,324
Palustrine Scrub/Shrub Wetland Conversion To:				
Development	-297	-280	-719	-296
Agriculture	0	-33	-159	-704
Upland	-3	-783	-197	-37
Palustrine Forested Wetland	10,816	57,626	54,957	122,149
Palustrine Emergent Wetland	30,185	42,727	36,153	26,295
Estuarine	0	0	0	0
Unconsolidated Shore	-16	7	1	4
Open Water	-407	310	-376	197
Net Over Change	40,277	99,574	89,661	147,607
Palustrine Emergent Wetland Conversion To:				
Development	-150	-1,190	-172	-127
Agriculture	0	-67	-534	-729
Upland	272	-1,210	-2,303	-455
Palustrine Forested Wetland	34,308	45,409	77,125	63,038
Palustrine Scrub/Shrub Wetland	-30,185	-42,727	-36,153	-26,295
Estuarine	0	0	0	0
Unconsolidated Shore	-62	-44	16	31
Open Water	1,634	-77	-2,315	-258
Net Over Change	5,816	-265	35,664	35,204

In contrast to coastal palustrine wetlands, net change in estuarine wetland acreage exhibited an inverse temporal pattern (Table X.15). Specifically, net gains of estuarine wetlands were observed between 1996 and 2006, while net losses were observed from 2006 to 2016. The type of land conversion that accounted for the majority of loss shifted considerably through time. Conversion of estuarine wetlands to agriculture and upland land accounted for 48% and 42% of losses from 1996 to 2001, respectively. Conversion to agriculture land accounted for 80% of estuarine wetland losses between 2001 and 2006, while conversion to development and upland accounted for 37% of losses each between 2006 and 2011. From 2011 to 2016, conversion to unconsolidated shore and open water were the leading sources of estuarine wetland losses, accounting for 38% and 32%, respectively.

Table X.15. Net loss or gain of North Carolina's estuarine wetland acreage by type of conversion between estuarine wetlands and other land cover classes. Positive values represent a net gain of estuarine wetlands to the specified land cover class and negative values represent a loss gain of the estuarine wetlands from the specific land class cover. Data Source: NOAA Coastal Change Analysis Program (C-CAP) 2016.

Time Period	Estuarine to:						Net Overall Change
	Development	Agriculture	Upland	Palustrine	Unconsolidated Shore	Open Water	
2011-2016	-15	0	-9	0	-31	-26	-81
2006-2011	-77	-1	-77	0	-54	146	-63
2001-2006	-16	-62	4	0	1	75	2
1996-2001	-6	-30	-26	0	252	400	590

Division of Water Resources

In NC, EMC has wetland standards (15A NCAC 02B.0231) that provide protection of wetland functions. Projects can impact wetlands if below the allowed threshold. If unavoidable, and a project meets other EMC rule criteria, a project may be permitted, but mitigation is required (15A NCAC 02H.1305). Impact thresholds are less than or equal to one acre in the coastal region, and less than or equal to 0.5 acres in the piedmont region. The DWR tracks wetland, stream and buffer impacts that are permitted through the 401 Wetland Program. According to NC DEQ's Basinwide Information Management System (BIMS), 17,984 acres of wetland impacts were permitted statewide through 12,386 issued 401 certifications and Isolated Wetlands and Waters permits between January 1, 1990 and December 31, 2019 (Figure X.41). The areas of the most impacted acres can be found in some of the coastal counties. The DWR permit data for the 20 coastal counties indicate that in the 1990s, most impacts were attributable to water dependent structures (marinas, docks, bulkheads), followed by dredging. From 2000 to 2010, there was a large increase in mining impacts. Since 2010, most impacts were associated with transportation (Figure X.42). Some of the impacts are offset by mitigation.

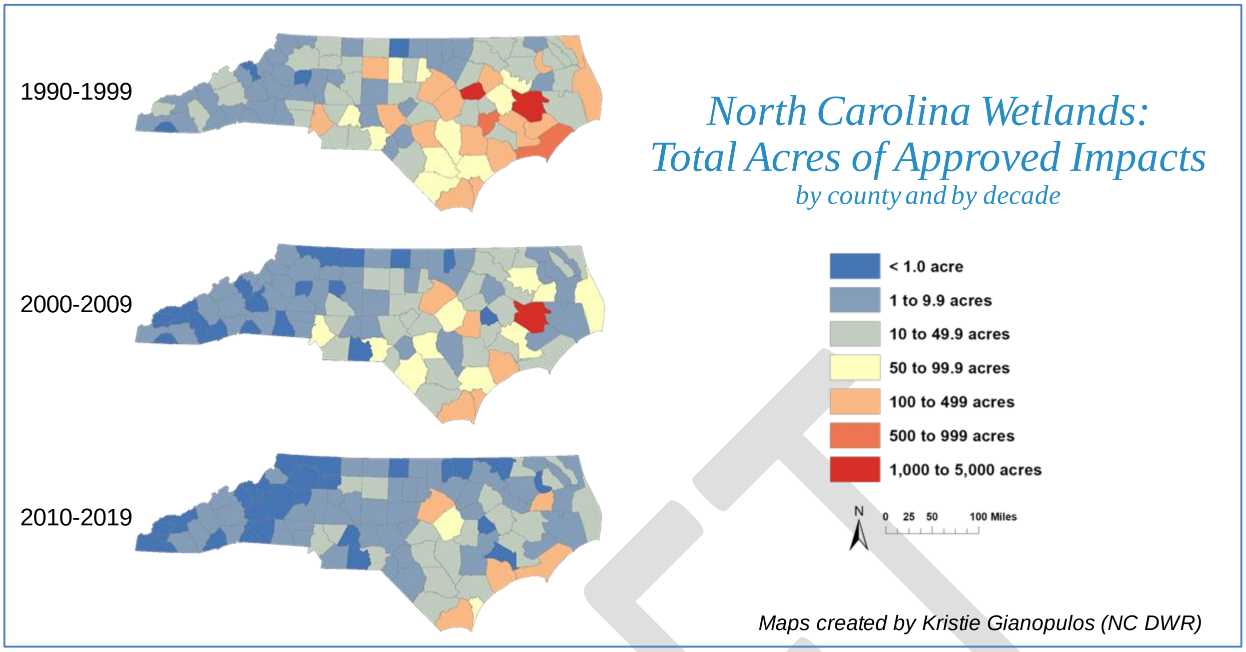

Figure X.41. Total acres of statewide approved impacts over the past 30 years (Source: A. Mueller, DWR).

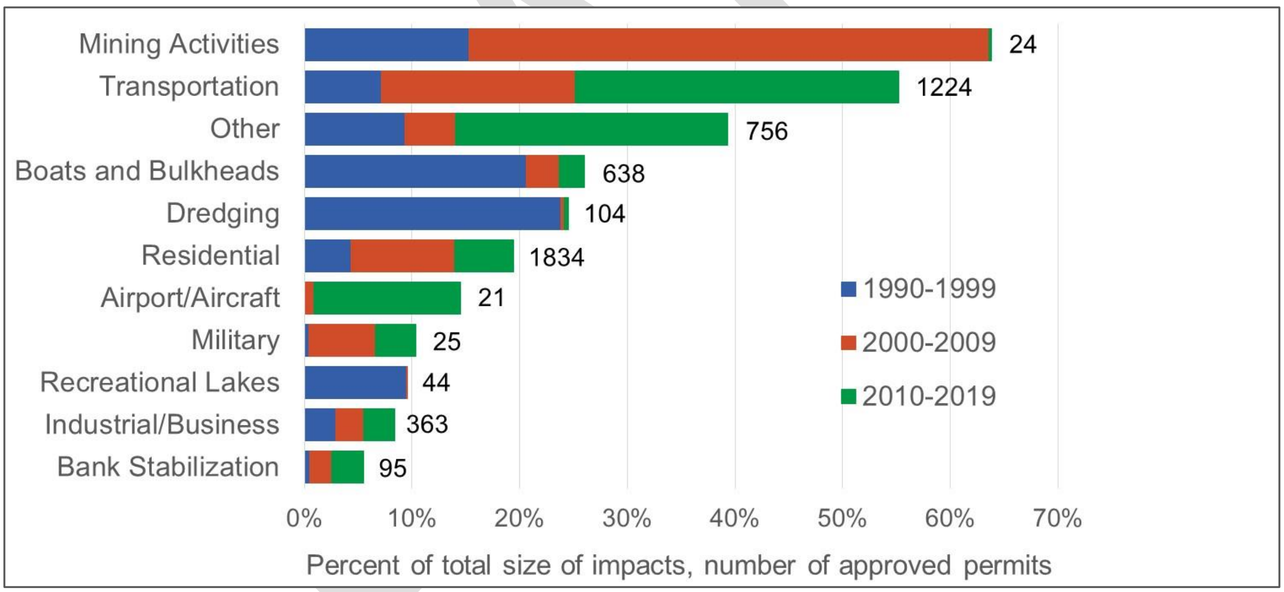

Figure X.42. Permitted wetland impacts by primary activity type in the 20 coastal counties, over the past 30 years (A. Mueller, DWR).

North Carolina's official wetland monitoring program was initiated by the Division of Water Quality (now DWR) in 2004. Since its inception, wetland monitoring conducted by DWR has been funded primarily by the USEPA Wetland Program Development Grants (WPDG). While the first grant primarily supported efforts to monitor headwater wetlands, subsequent grants have provided funding to monitor basin wetlands, riverine swamp forests, and bottomland hardwood forests located across multiple watersheds. Between 2004 and 2015, projects funded largely by the USEPA resulted in the monitoring of 248 wetland sites (Figure X.43). Due to the grant duration and project objectives, most (147 of 248, or 59%) were monitored for one year or less.

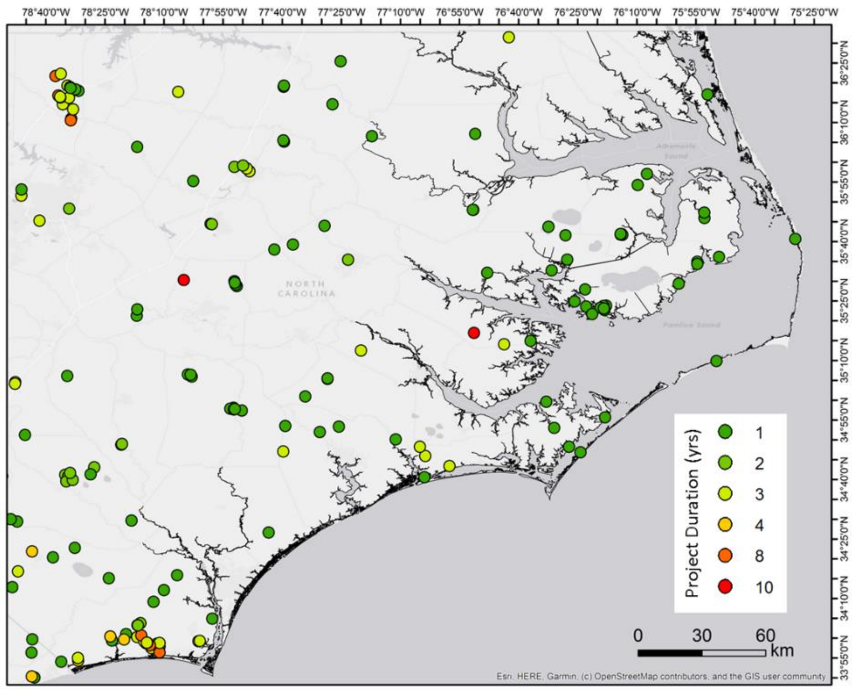

Figure X.43. Location and sampling duration of wetland monitoring projects conducted by DWR and partners between 2004 and 2015.

Since the dissolution of the WPD, wetland monitoring efforts by state agencies have continued, but at more limited scales. Wetland projects ranged from field evaluation of restored mitigation wetlands, to study of headwater wetlands, characterizing isolated wetland hydrologic connectivity, water quality, and biota, and assessing use of natural wetlands for stormwater assimilation, among others (http://www.ncwetlands.org/research/wetland-project-summaries/). However, these were short-term studies. The Wetland Program Plan (NC WPP) is developed on five year cycles to guide actions to research and protect wetlands. The plan is currently being updated and will be finalized in 2021. The Division of Mitigation Services (DMS) compiles monitoring reports for compensatory mitigation projects, and the Wildlife Resource Commission (WRC) has conducted monitoring to assess abundances of select fauna of interest.

In contrast to the short-term monitoring typical of EPA-funded projects that took place between 2004 and 2015, the North Carolina Sentinel Site Cooperative (NCSSC), one of five cooperatives established throughout the US with NOAA funding in 2012, has established long term monitoring of coastal habitats in eastern North Carolina. The cooperative consists of partners from NOAA, North Carolina Coastal Reserve, DCM, NC Sea Grant, Department of Defense, National Park Service, the North Carolina Aquarium at Pine Knoll Shores, academia, and town governments, with the goal of leveraging resources across organizations to provide stakeholders with information to address sea level rise and coastal inundation. A component of the work the NCSSC conducts is the monitoring of coastal habitats to address impacts of sea level rise. This has entailed leveraging existing and establishing new sites for the long-term monitoring of elevation change using surface elevation tables (SET), which are portable mechanical instruments that provide high-resolution measurements of elevation change within wetland sediments (Lynch et al. 2015). There are currently over 125 SETs throughout coastal North Carolina generating information on the degree to which coastal marshes are keeping up with sea level rise (Figure X.44).

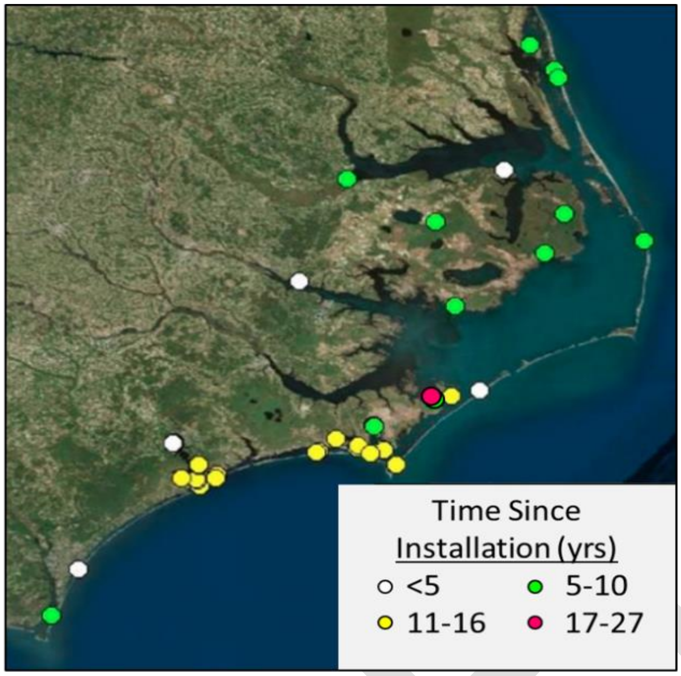

Figure X.44. Surface elevation table (SET) locations in NC. Source: J. Davis, NOAA NCCOS.

1.4.5. Hard Bottom

Background

Oceanic hard bottom is the primary habitat for offshore marine organisms on the continental shelf of North Carolina (Mallin et al. 2000, Riggs et al. 1996). These exposed structures functions as foundation for sessile invertebrates and algae, refuge for free moving benthic invertebrates and vertebrates, as well as juvenile, bait, and economically important fishes (Chester et al. 1984, Grimes et al. 1982, Mallin et al. 2000).

Extent in North Carolina

Hard bottom in NC is limited to specific areas of the continental shelf with 90% of existing hard bottom occurring south of Cape Hatteras. These natural and important areas are susceptible to overfishing due to their scarcity and abundance of inhabitants. Parker et al. (1983) estimated the amount of natural hard bottom reefs between Cape Hatteras and Cape Fear to be around 504,095 acres, or 14% of the substratum. Nearshore hard bottoms were considered to be in “good general” condition overall in 1998 (SAFMC 1998). Although information exists on the distribution of hard bottom off the NC coast (SEAMAP-SA 2001; Moser and Taylor 1995; Reed 2004; Udouj 2007), little information is available to evaluate the status and trends of hard bottom habitat in state territorial waters.

While some surveys have been conducted by federal agencies and the energy exploration industry, the exact extent and distribution of productive live bottom habitat on the continental shelf north of Cape Canaveral is unknown. Although a number of attempts have been made, estimations of the total area of hard bottom are confounded due to the discontinuous or patchy nature of the habitat type. Henry and Giles (1980) estimated about 4.3% of the Georgia Bight to be hard bottom, considered an underestimate. Miller and Richards (1980) reported that live bottom reef comprises a larger area of the South Atlantic Bight. The method used to determine areas of live bottom involved the review of vessel station sheets from exploratory research cruises. Anecdotal information from fishermen and residents in coastal NC suggests that many nearshore hard bottom sites in the mid-twentieth century are now covered by sand, reducing the abundance of fish in these areas.

Some areas have already been lost to the effects of beach nourishment. Hard bottom habitat off the coast of Wrightsville Beach was buried under two to six inches of sand through erosion off the nourished beach. These once productive fishing grounds no longer support the number or diversity of fish they once did. The observed declines in species abundance and richness lead researchers to conclude that the conflict between beach nourishment and hard bottom productivity is a very serious conflict that will only get worse (Greene 2002; Riggs et al. 1998).

Artificial Reef Program

As of 2020, DMF's Artificial Reef Program manages 63 artificial reefs including 22 estuarine reefs, 15 of which serve as oyster sanctuaries, and 43 offshore reefs (13 in state waters and 30 in federal waters) with the goal of supporting and functioning similarly to nearby natural reefs while providing user access opportunities (Figure X.45). The artificial reefs have been shown to support a similar community as natural reefs on multiple metrics (Paxton et at. 2017; Rosemond 2018). The artificial reefs also provide habitat for top predators and fishes at the edges of their distribution ranges (Paxton et al. 2019a; Paxton et al. 2019b).

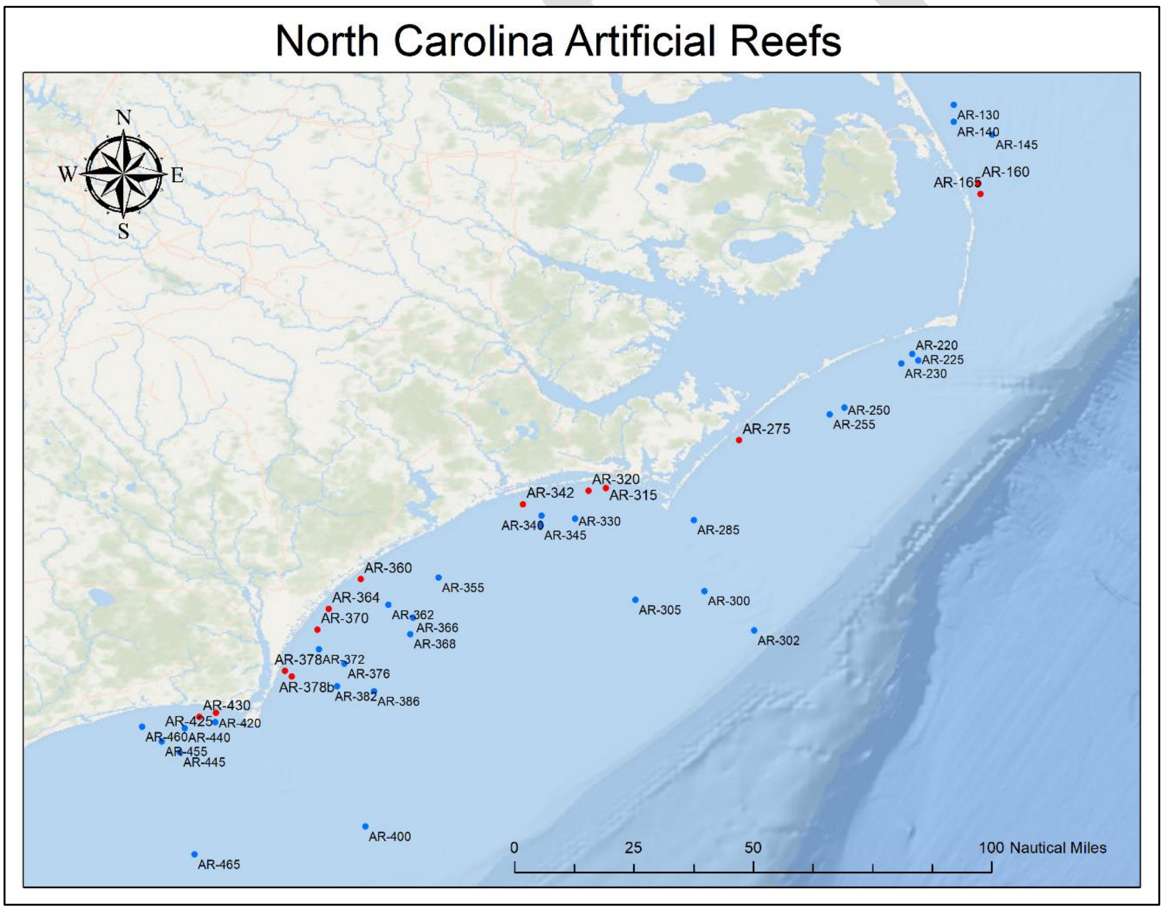

Figure X.45. Map of all offshore artificial reefs in North Carolina. Blue sites are located in federal waters and red sites are located in state waters.

Currently, the artificial reefs in NC are being monitored by the Artificial Reef Program for material stability and major storm effects on a yearly basis. These reefs are also the focus of research supported by a CRFL grant to compare them to neighboring natural reefs being conducted by North Carolina State

University (NCSU) and the National Centers for Coastal Ocean Science (NCCOS). The goal of this research is to determine usage of artificial and natural reefs by fishes at fine and broad scales as well as develop tools for improved monitoring and planning of artificial reef construction. The NCCOS is also in the process of prioritizing the offshore areas of NC, SC, and GA to survey more of the natural and artificial reefs in the areas.

1.4.6. Soft Bottom

Background

Marine sediments constitute one of the largest habitat types on earth, covering roughly 80% of the ocean bottom (Lenihan and Micheli 2001). The only requirement for the persistent presence of soft bottom is sediment supply. These soft sediment environments are complex ecosystems containing strong physical gradients that affect the distribution of species and physicochemical conditions (Schenone and Thrush 2020). Environmental characteristics, such as grain size, salinity, DO, depth, and flow conditions affect the condition of the habitat and the organisms using it. The characteristic common to all soft bottom is the mobility of unconsolidated sediment (Peterson and Peterson 1979). Soft bottom is in a constant state of flux, as other habitats expand or contract. The loss of more structured habitat, such as SAV, wetlands, and shell bottom, leads to gains in soft bottom habitat. Gains in new soft bottom habitat may not be as beneficial as mature soft bottom habitat. An analysis of satellite images (1984-2016) that mapped the global extent of tidal flats, defined as sand, rock, or mud flats that undergo regular tidal inundation, found that this habitat type occupies over 31 million acres worldwide (Murray et al. 2019). About 70% of the global extent of tidal flats is found in three continents (Asia, 44%; North America, 15.5%; and South America, 11%), with 49% being concentrated in just eight countries (Indonesia, China, Australia, the United States, Canada, India, Brazil and Myanmar). It is estimated that approximately 16% of tidal flats were lost between 1984 and 2016 due to coastal development, lack of sediment transport, increased erosion, and sea level rise (SLR).

Extent in North Carolina

In NC, soft bottom covers approximately 90% of the estuaries and coastal rivers (Riggs 2001). As part of the Strategic Habitat Area (SHA) assessments, soft bottom area has been described for all CHPP regions and was usually derived using a combination of the DCM's estuarine shoreline GIS layer, the NOAA bathymetry contour dataset, and the NWI dataset (Table X.16; NCDMF 2009, 2011, 2014b, 2018). As expected, the most extensive amounts of soft bottom can be found in CHPP regions 1 and 2, which include the vast open waters of the Albemarle and Pamlico sound systems. The deep soft bottom (>6 ft) is dominant with at least more than twice the amount of shallow soft bottom (≤6 ft) in every region. However, due to overlapping inlet regions, and the resolution of the data used this is an over estimation of soft bottom habitat in NC. No targeted mapping efforts exist for soft bottom and bathymetry data are out dated. Therefore, it is not possible to quantify how the extent of soft bottom habitat has changed through time.

Table X.16. Estimated acreage of estuarine and marine shallow, deep, and unknown depth soft bottom habitat within CHPP regions of North Carolina (Source: NCDMF 2009, 2011, 2014b, 2018). Due to overlapping inlet regions, and the resolution of the data used this is an over estimation of soft bottom habitat in NC

CHPP Regions	Shallow Soft Bottom (≤6 ft)	Deep Soft Bottom (>6 ft)	Soft Bottom (Unknown)	Total Soft Bottom
	Acres	Acres	Acres	Acres
Albemarle Sound to Northeastern Coastal Ocean (1)	232,608	610,733	64,908	908,248
Pamlico Sound System (2)	193,417	1,172,449	63,887	1,429,753
White Oak River Basin (3)	128,282	242,402	10,996	381,680
Cape Fear River Basin (4)	31,951	184,556	13,978	230,485
Total				2,950,166

Benthic Community

The condition and quality of soft bottom habitat can affect species abundance and diversity of the benthic community and could be considered a more important factor for soft bottom than extent. Sediments in soft bottom habitat can accumulate both chemical and microbial contaminants, potentially impacting benthic organisms and the community structure. Tidal creeks are sensitive to various aspects of human activity, but sensitivity depends on the size and location of the creeks. Because tidal creeks are the nexus between estuaries and land-based activities, the potential for contamination is great. Smaller intertidal creeks closer to headwaters demonstrate greater concentrations of nonpoint source contamination than larger systems closer to the mouth (NOAA 2008).

The USEPA NCCA is the only regular monitoring of soft bottom in NC. In 2010, the biological quality of 77% of the waters in the Southeast coastal region was rated as good based on the benthic index (Figure X.46; USEPA 2015). Based on the sediment quality index, 65% of the Southeast Coast region was rated good, and sediment toxicity findings indicated that 81% were in good condition. The contaminants that most often exceed the lowest observed adverse effect level (LOAEL) thresholds were selenium, mercury, arsenic, and (in rare instances) total DDTs.

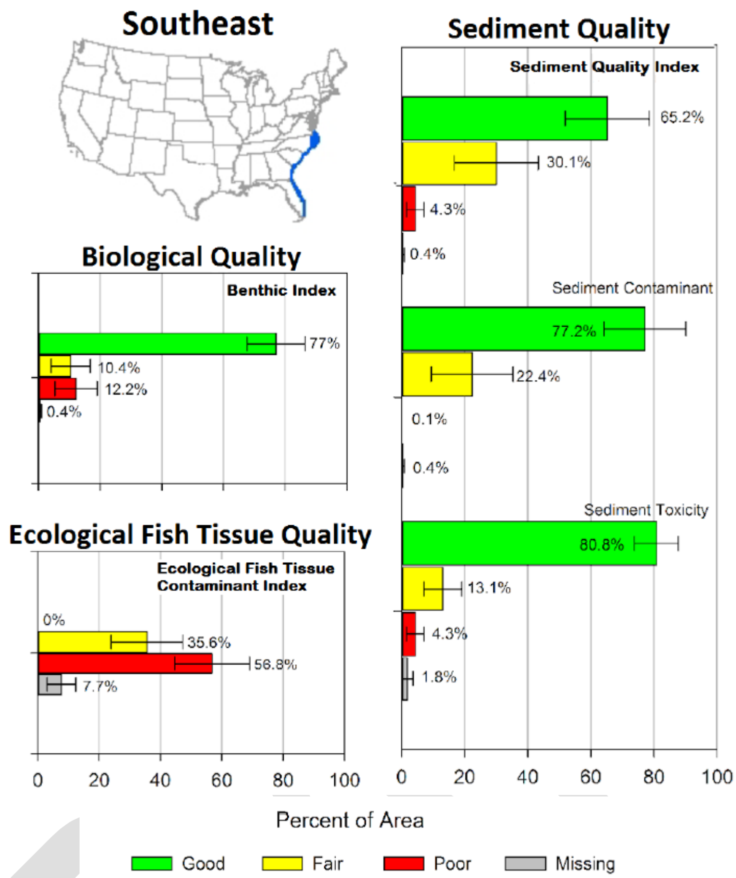

Figure X.46. The USEPA National Coastal Condition Assessment (NCCA) 2010 biological, sediment, and ecological fish tissue quality index results for the Southeast Coastal region. Bars show the percent of coastal area within a condition category for specific indicators. Error bars represent 95% confidence intervals. Note: The sum of percent of area for each indicator may not add up to 100% due to rounding. (Source: USEPA 2015).

Between 2005–2006 and 2010, there was a significant decrease of 27% in the area rated good for sediment quality. The sediment contaminants indicator appears to be the driver for this change, while the sediment toxicity indicator shows an opposite result. For the benthic quality index, there is a large, statistically significant increase of 14% in waters rated good between 2005–2006 and 2010 (Figure X.47). While these results might appear contradictory, the sediment and benthic indicators do not necessarily respond to stressors in the same manner. As additional data are collected and analyzed for the NCCA 2015, clearer patterns may emerge. However, in NC it has been shown that sites having higher concentrations of contaminants have lower indices of biotic integrity (Hyland et al. 2004).

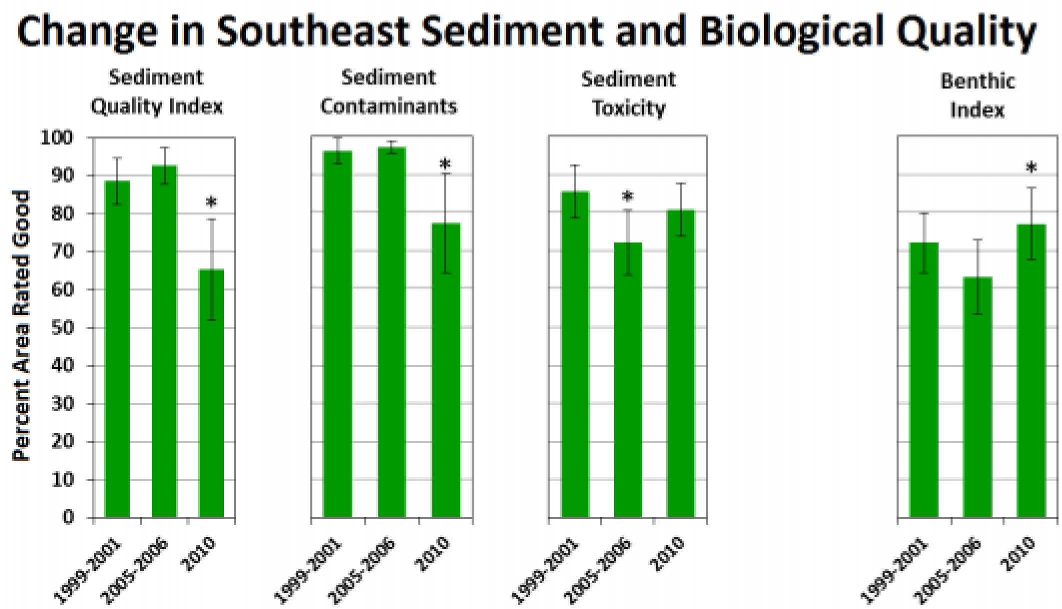

Figure X.47. Comparison of the percent area rated good for sediment and biological quality over three periods in the Southeast. Note: Asterisks indicate statistically significant change between periods.

Using synoptic data on sediment chemistry, toxicity, and macroinfaunal community structure from 175 subtidal stations sampled during the summers of 1994–1997, one study evaluated the sediment quality of North Carolina estuaries (Hyland et al. 2000). The study area included Currituck, Albemarle, and Pamlico Sounds; estuarine portions of the Chowan, Roanoke, Tar-Pamlico, Neuse, New, and Cape Fear rivers; and numerous smaller tributaries. Over half (54 ± 7%) of the surveyed area had high sediment quality characterized by healthy benthic assemblages and low levels of sediment contamination and toxicity. The remaining 46% showed evidence of significant stress in one or more of the above mentioned sediment-quality components. Only 19% of the total area showed evidence of an impaired benthos coupled to significant pollution exposure (high sediment contamination, toxicity, or both). Impaired benthic condition was more closely linked to sediment contamination than to low dissolved oxygen (based on instantaneous oxygen measurements). The most prevalent contaminants were metals (arsenic, mercury, chromium, and nickel); pesticides (lindane, dieldrin, DDT, and DDT derivatives); and total PCBs. Degraded condition in all three sediment quality components occurred in <10% of the study area, suggesting that the benthos in a small (yet ecologically significant) percentage of total estuarine area are affected by high sediment contamination. This study found the spatial extent of sediment contamination and toxicity in NC to be much less compared to other U.S. coastal regions where similar studies have been performed.

Since 1978, DWR Bioassessment Branch has been sampling benthic macroinvertebrates in the wadeable and non-wadeable lotic waters of the state. To date, no benthic sampling occurs within the estuarine waters.

1.5. Discussion

The first step for coastal resource managers is to raise public awareness of the problems caused by degradation and destruction of the natural environment and identify the social causes of environmental damage (O'Higgins et al. 2020). The complex interactions between and within NC's coastal habitats, the estuarine ecosystems as a whole, and the human population has to be considered by coastal resource managers. This creates the need for regular standardized monitoring and assessments of these habitats in order to quantify their extent and condition using habitat and ecosystem indicators. Ecosystem indicators are measures of a state or level that informs about what is happening in the environment by using a set of metrics, or quantitative measures that provide a standard used to assess an ecosystem indicator, to detect changes in status and trends over time. This information is then used to educate the public about the condition of NC's coastal habitats, inform protection and restoration efforts, and evaluate the effectiveness of management actions and strategies to achieve the CHPP goal of *the long-term enhancement of coastal fisheries associated with coastal habitats*.

The background section summarizes the most up to date and available monitoring and assessment data to describe the current status and trends of coastal habitats. However, there is no formal process in place for continuously monitoring or establishing standardized ecosystem indicators, thresholds, or reference points for coastal habitats. Ecosystem indicators including quantitative biological, chemical, physical, social, or economic measurements can be used as proxies of the conditions of attributes of the coastal habitats, the estuarine ecosystem, and socio-economic systems (Kurtz et al. 2001; USEPA 2008;). The integration of social and ecological information relevant to stakeholders and managers is an essential component when trying to reach management goals and remediate environmental impacts (Figure X.48; Gómez et al. 2016; Elliot and O'Higgins 2020).

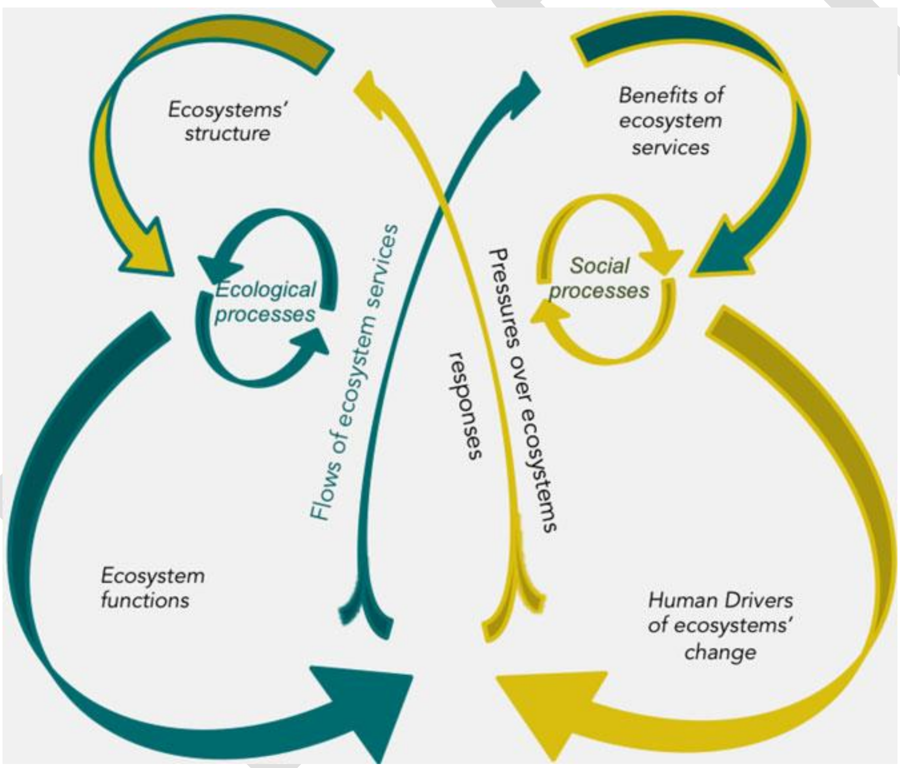

Figure X.48. The butterfly diagram, a new model for the assessment and design of Ecosystem-Based Management. Supply side is shown in blue, demand side is shown in yellow. Social-ecological systems as interlinked, complex, adaptive systems. (Source: Gómez et al. 2016)

The APNEP has taken significant steps towards identifying coastal habitat and estuarine ecosystem indicator metrics in NC in their comprehensive ecosystem assessment of the Albemarle-Pamlico region (APNEP 2012a; APNEP 2012b). This and similar efforts could be the foundation to identify the suite of indicators to be reported for coastal habitat types as well as by CHPP regions and coastwide (Martinez-Crego et al. 2010; Goodin et al. 2018). Once indicator metrics with reference points or thresholds are selected, the monitoring needs and data gaps in the extent, resolution, and frequency of the data needed to calculate those metrics can be addressed. Then the condition of coastal habitats, as well as overall estuarine and regional conditions, can be reported in regular intervals. With the push toward EBM, this would give managers the ability to assess changes over time and develop performance criteria for management actions while also creating a condition report, vital signs, or report card, for communicating coastal habitat and ecosystem conditions to the public (USEPA 2015; GADNR 2019).

1.5.1. Monitoring Needs and Data Gaps

Habitat indicators metrics by coastal habitat types, CHPP regions, and coastwide should be defined by agency and monitoring program staff along with regional experts and academics. Through this process, monitoring needs and data gaps should be determined and addressed to obtain the best available continuous data to inform these metrics. Existing DEQ programs and efforts should be evaluated and standardized whenever possible, and the expansion of existing programs should be explored to fill data gaps before initiating new programs. While some of these efforts are currently underway and several data gaps and monitoring needs have already been identified, this is a vast undertaking that should be done systematically and with the best available data and technologies while also taking into consideration the funding, staff, and resource limitations.

Water Column

Water quality monitoring is of the utmost importance for determining the health and condition of the estuarine ecosystem. Poor water quality can have significant impacts on the extent and distribution of coastal habitats and the fauna that use them. Having the ability to determine long-term temporal and spatial trends of water quality indicators and cause and effect relationships are critical for coastal managers. This information is needed to make informed management decisions and evaluate the effectiveness of management actions. While several state and federal agencies and academic institutes collect water quality data at various spatial and temporal scales, DWR's AMS is the most comprehensive long-term, continuous monitoring program along NC's coast. However, the 149 active monitoring stations within the CHPP boundaries are mostly concentrated in riverine and upper estuarine waters with some large spatial gaps existing along the coast. Currently, except for Albemarle Sound, there are no AMS stations in the sounds, at the mouths of the White Oak, New, and Cape Fear rivers, or many of the southern tidal creeks. Concerns for this lack of stations, especially in New River, were discussed by the DMF Shrimp Fishery Management Plan Advisory Committee at their March 2021 workshops.

Most AMS stations are monitored monthly and a core suite of indicators are measured at all stations. These include water temperature, specific conductance, pH, turbidity, total suspended solids (TSS), dissolved oxygen (DO), and fecal coliform. Additional indicators may be included depending on site-specific concerns such as stream classification, discharge types, and historical or suspected issues. Examples of site-specific indicators, which are monitored monthly or quarterly, include salinity, water clarity, flow, nutrients (NH_3, NO_2+NO_3, TKN, TP), fluoride, sulfate, total hardness, color, oil and grease, and chlorophyll a. These and all other water quality parameters should be evaluated to determine indicator metrics for tracking the status and trends of the water column habitat. Water quality indicator metrics may also involve other coastal habitats that have threshold tolerances like SAV and shell bottom. Expansion of the AMS to fill the identified spatial data gaps along with the addition of selected parameters chosen for indicator metrics will increase the ability to determine causal relationships between water quality and the natural and human-induced impact to the estuarine system, including fish populations. These data can be used, not only to track the status and trends of the water quality of coastal NC, but also to evaluate the effectiveness of a suite of management actions and allow for the potential for adaptive management of other coastal habitats like SAV and shell bottom that exhibit threshold tolerances. However, like most existing monitoring programs, funding and staff resources are a limiting factor. In addition to the AMS station monitoring, environmental conditions and evaluations associated with a response to fish kills, algal blooms, or other environmental investigations in coastal waterbodies requires dedicated staff.

Algal blooms and fish kill events often involve a host of factors and underlying causes. Therefore, it is crucial to gather as much information as possible surrounding an event from all involved parties. In 1996 the DWR Water Sciences Section (WSS), in consultation with Regional Office staff, Wildlife Resources biologists, and DMF personnel, instituted a new fish kill investigation procedure to be used by the DWR Regional Offices, Monitoring Teams, and other agencies to collect and track information on fish kills throughout the state. Fish kill and fish health data are recorded via standardized methods and sent to WSS where the data are reviewed. Fish kill investigation reports and supplemental information are compiled in a central database where the data can be managed, retrieved, and reported to state officials, scientists, and other concerned parties. Similar efforts have been undertaken with algal blooms, but a standardized procedure for algal bloom investigation across involved agencies is needed to collect the appropriate metrics at the time of the event, which can often be hard to capture. With increased reporting of both fish kills and algal blooms through the online portal and hotline (https://survey123.arcgis.com/share/c23ba14c74bb47f3a8aa895f1d976f0d?portalUrl=https://ncdenr.maps.arcgis.com and Hotline #: (800) 858-0368), cross-training staff to perform these investigations is of increasing importance.

Public health concerns arise from some algal blooms that are harmful (HABs), producing toxins such as microcystin that can cause adverse health effects. With technical support from DWR, local health departments and the NC Department of Health and Human Services, appropriate responses (swimming closures, contact advisories, issuance of public notifications, etc.) need to be determined. Due to these concerns, DMF's SSRWQ is currently conducting a pilot study and has prepared a Marine Biotoxin Contingency Plan to quickly respond to the emergence of any harmful algae species within State waters that may threaten the health and safety of shellfish consumers. The plan includes sentinel site monitoring for early warning of potential issues, the actions that will be taken to protect public health, and the steps that will be taken to reopen areas to shellfish harvest once the threats have subsided. This plan will begin to collect baseline data in areas not previously covered while complementing DWR's current monitoring efforts. Tracking the number of fish kills and algal blooms could prove to be useful indicator for overall estuarine ecosystem health, as well as development of criteria for determining success of management actions.

Shell Bottom

Despite what is currently understood regarding the value and necessity of retaining a healthy oyster population in NC's estuaries, there remains several critical knowledge gaps that limit management's ability to confidently evaluate restoration success, oyster reef performance, and estimate population sizes (stock assessment). There is a lack of contemporary, high resolution maps of subtidal hard bottom habitat that naturally occur throughout waterbodies suitable for sustaining oyster populations. There is also limited information regarding the impacts of the commercial oyster dredge fishery on natural oyster reefs, its ability to recover post-harvest, and the proportion of annual harvest that originates from cultch planted reefs.

Through grant funding, DMF is currently working in collaboration with NCSU, The Nature Conservancy, and local oystermen to conduct research in support of a stock assessment survey for oysters in NC (Bowling et al. 2021 unpublished). To best assess the subtidal oyster populations, a fishery-independent methodology was developed and piloted across natural reefs in the Pamlico Sound. This methodology makes use of side-scan sonar, diver excavation surveys, and oyster dredges to establish oyster densities, new mortality, size-frequency demographics, and reef condition. This can result in an ideal overall representation of the area's oyster reefs due to careful calibration of the oyster dredge using diver surveys, standardized sampling methods, and the incorporation of gear experts from the commercial fishery. While the typical oyster dredge has low efficiency, this research is demonstrating how it can be effectively used to sample large areas and generate a robust overall average density and abundance estimates.

While this work is focused on modifying DMF's subtidal oyster management trigger sampling program for use in a stock assessment, these outcomes can also be used to standardize subtidal oyster sampling methods and metrics across all programs that encounter subtidal oysters, including oyster sanctuary and clutch planting monitoring. A similar gear comparison pilot study on cultch planted reefs in Stump Sound will be conducted during the 2021 season. Data from this pilot study will be used to assist DMF staff in determining future monitoring of cultch planted reefs to update the Spatfall Evaluation Program (P610). Standardizing metrics across the programs that sample subtidal oysters will provide more robust data to be used in the stock assessment that will be used to better track the status and trends of NC's subtidal oyster population. Along with standardized metrics, modified and expanded monitoring designs will also improve siting of future oyster sanctuary and cultch planting sites and the ability to report metrics of success for the rehabilitative efforts.

Methods to evaluate and monitor NC's intertidal oyster population are also being evaluated. NC's intertidal oyster reefs remain difficult to access and navigate for monitoring due to the short tide windows that they are exposed and the shallow muddy characteristics of the habitat. To address such challenges, remote sensing technology paired with traditional quadrat ground-truth sampling is being explored. Remote sensing by use of Unmanned Aerial Systems (UAS) has considerable potential to radically improve environmental monitoring (Manfreda et al. 2018). Compared to traditional air or space borne remote sensing, UAS-mounted sensors provide high spatial detail over relatively large areas in a cost-effective way and an entirely new capacity for enhanced temporal retrieval. These new survey methods can be used to evaluate the ability to detect changes in density, size-frequency demographics, and reef footprint over time (Bowling et al 2021 unpublished). Preparations are underway to start an updated bottom mapping program. This new shellfish mapping program pilot study (Program 636 Remote Sensing Estuarine Bottom Habitat Mapping) will use the remote sensing technology in conjunction with ground-truth sampling to obtain higher resolution mapping with standardized metrics with a focus on the natural intertidal oyster populations along the NC coast.

During the initial pilot study phase (2021-2022), 12 sites across the coast were selected to be mapped and sampled to develop best practices for drone monitoring and standardize ground-truth sampling methods. The sites are 100 acres and were chosen to represent the differing geography, hydrography, and available resource across the CHPP regions. All or a subset of these sites may be selected as long-term monitoring sites, or sentinel sites. The same 24 bottom type strata from the original Estuarine Bottom Habitat Mapping Program will be used, but may be modified and ground-truth sampling methods will be standardized across all DMF subtidal and intertidal oyster sampling programs whenever possible to provide more robust data for an oyster stock assessment to better track trends in the NC oyster population. A new and improved rapid assessment method would allow for a better understanding of the status and trends of the intertidal oyster population in NC, while also producing metrics that could also be used to evaluate and support the effectiveness of management actions.

Initial sampling for the subtidal portion of the study found notable impacts from hurricanes Florence and Dorian were also observed. These observations included heavy sedimentation on oyster reefs, strong water column stratification, hypoxic and anoxic conditions, and reduction in reef material. This sampling showed an overall decrease in oyster density during the same time period. In some cases, a

90% decrease in oyster density per square meter across study reefs were found, with an average overall decrease in density of 64% for the entire study area (Bowling et al 2021 unpublished). With a projected increase in the strength and intensity of tropical storms, fishery-independent surveys will be important for monitoring water quality and storm-induced mortality. While further study is needed, oyster reef size, profile, and location are thought significantly influence the severity of storm disturbance and resulting oyster mortality (Bowling et al. 2021 unpublished). This information could prove to be critical in providing resilience to oyster sanctuary and cultch planting sites through improved site selection and construction criteria.

Submerged Aquatic Vegetation (SAV)

Understanding the distribution and health of SAV in NC is critical to understanding the dynamics of shifts in SAV species extent, distribution, and compositions. As previoulsy described, mapping of SAV has occurred at irregular intervals over the last 40+ years by several different agencies and universities, across different extents, and with varying methologies and resolutions. A comprehensive monitoring and assessment program for SAV should be developed using the best available technology. The use of the most comprehensive, highest resolution, and cost effective methods available should be explored and used. This program should be developed by a team of partners, and should include a full-scale, routine (occurring at least every five years), coast-wide assessment and monitoring program. Sentinel sites should be re-evaluated and expanded along the coast, with regular ground-truthing using standardized metrics (i.e. water quality, species composition, density, and condition). This will allow managers to account for changes in SAV over time, giving the ability to evaluate the success of management actions and determine causative relationships between changes in SAV species extent, distribution, and composition. Through regular monitoring and assessment, protection of this habitat can be improved and targeted, benefiting the diversity and resiliency of the entire coastal ecosystem.

Initial steps towards a coastwide, long-term, standardized SAV monitoring plan have been undertaken by APNEP (APNEP 2021). The APNEP monitoring plan provides the information needed to initiate an SAV monitoring strategy for the Albemarle-Pamlico Estuarine System (APES). The assessment questions used to guide the development of the monitoring design were: 1) how is SAV condition changing in estuarine waters? and 2) are estuarine water quality conditions suitable to sustain the ecosystem services provided by SAV species? The SAV monitoring recommendations within the SAV monitoring plan for APES were based on a series of APNEP SAV Team high-salinity subcommittee and low-salinity subcommittee meetings during September and October 2020. The APNEP SAV team includes APNEP and DMF staff, as well as SAV experts and researchers from across the NC coast. A three-tiered hierarchical framework for SAV monitoring was adopted by both subcommittees and the APNEP Leadership Council to guide the development of recommendations (APNEP 2021).

This method was first tested in northeastern U.S. and has since been applied in other regions, including the Gulf of Mexico, and is an efficient and feasible way to detect and predict changes in seagrass systems in relation to management actions (Neckles et al. 2012; Handley et al. 2018). In short, Tier 1 monitoring characterizes a few ecosystem properties simultaneously over large spatial scales, typically using satellite or remote sensing methods which is useful to quantify the extent and distribution of the SAV across the coast and geographic regions. Next, Tier 2 monitoring addresses specific environmental issues or ecosystem properties at a higher resolution, generally using ground-based approaches. This allows for monitoring of a limited number of metrics at a large number of sites across the coast or geographic regions. Tier 2 data can be used to quantify stressor/response relationships, and produce estimates of the ecological condition of resources over broad areas, or the quality of the system as a function of physical, chemical, or biological parameters. However, Tier-2 data are generally insufficient for developing predictive capabilities.

Finally, Tier 3 monitoring addresses a larger number of metrics at a much smaller number of locations or subset of locations (e.g., sentinel sites). Intensive monitoring of drivers of change, ecosystem responses, and ecological processes at Tier 3 focuses on determining cause and effect relationships and can be used to help explain system wide changes. Both Tier 1 and Tier 2 data can influence targeted monitoring in Tier 3 and can be used to inform the adaptive management process (Neckles et al. 2012; Handley et al. 2018; APNEP 2021).

Due to limited funding and staff resources, the APNEP monitoring plan proposes a rotational monitoring design, where one SAV region in the APES would be monitored per year until all regions were monitored for a year, at which time the rotation would begin again (Figures X.35-X.39; APNEP 2021). The exact sampling design, including sampling numbers, site selection, sampling techniques, and collected metrics for Tier 2 and Tier 3 monitoring, will be determined prior to the 2021 monitoring season. Once the three-tiered monitoring framework in the APNEP SAV monitoring plan is established in the high and low salinity regions within APES, this monitoring plan could be expanded to include the southern SAV regions of the state outside of the APES (Figures X.40-X.41). However, like most monitoring, dedicated funding and staff are needed to ensure the long-term continuation of coastwide SAV monitoring. This monitoring is crucial to the understanding of the extent and condition of NC's SAV, as well as supporting management actions and decisions.

Wetlands

Comprehensive inventories of natural resources are recognized as critical components for informed management, policy, and conservation actions. Wetland maps are fundamental to wetland inventories, which are critical to management, restoration, protection, and informed development. Inventories informed by robust mapping efforts provide managers the information needed to assess the impacts of anthropogenic activities, changes over time that are attributable to natural phenomena, and the outcomes of management actions and restoration efforts. Consequently, shortcomings in wetland mapping, either in their resolution or comprehensiveness, can impede the development of comprehensive wetland inventories, pose a challenge to conducting robust environmental impact assessments, and broadly hinder data-drive natural resource management. Therefore, safeguarding NC's natural resources, while allowing for sustainable development, hinges on the collection and availability of comprehensive data on the distribution, characteristics, and function of NC's wetlands, 95% of which occur within the coastal plain.

The two primary wetland mapping sources that provide coastwide wetland distribution data include DCM's Wetland Inventory, and the National Wetland Inventory (NWI). The NWI produces wetland and deepwater habitat maps throughout the United States using photo-interpretation of aerial imagery and is the most extensive inventory of wetlands in the United States. A major shortcoming of the use of aerial imagery is the time lapse between image acquisition and production of wetland maps (Ramsey and Laine 1997). Further, the accuracy of imagery interpretation that informs NWI maps coming from multiple sources, is dependent on the quality of the imagery, availability of ground-truthing data, and repeatability by photo-interpretation analysts.

The DCM created a coastwide wetland inventory in the mid-1990's using NWI data, landcover classification from satellite imagery (Landsat data), and county-level soils data. The resolution and accuracy of DCM's wetland inventory, along with the older age of the imagery limits the products utility today (K. Richardson, NOAA, personal communication). The United States Geological Survey (USGS) and NOAA have federal mapping efforts related to wetlands. NOAA's C-CAP inventories coastal intertidal areas, wetlands, and adjacent uplands on one- to five-year intervals at a spatial resolution of 30 x 30 meter pixels using Landsat data, aerial photography, and field observations (Burkhalter et al. 2005).

Landsat data remains challenged by the relatively long period between revisits (16-18 days), cloud cover obstructing data collection, and shadows confounding interpretation (Wijedasa et al. 2012). As a result, the C-CAP has an accuracy target of 85% overall and 80% per habitat class (McCombs et al. 2016).

National and state inventories for land cover and wetlands are important tools used to formulate and evaluate the effectiveness of wetland policies and are integral to models used to predict the aerial extent of wetlands under a variety of future scenarios (Mahdavi et al. 2018). Therefore, the accuracy and resolution of these datasets have cascading effects throughout natural resource management and the research by which it is informed. While the spatial and temporal resolution of current NOAA C-CAP data has proven valuable for detecting large-scale changes in wetlands, particularly when the conversion occurs between distinct land cover types, numerous studies using higher-resolution imagery have documented wetland conversions that were not depicted using C-CAP data (Bhattachan et al. 2018; Magolan and Halls 2020). Fortunately, there are efforts underway by NOAA C-CAP to generate spatially robust, high resolution (1m x 1m pixel) land cover inventories and map products. High resolution NOAA C-CAP mapping remains limited to a select few partner cost-share pilot projects around the country (N. Herald, NOAA, personal communication). While nationwide one-meter resolution mapping is a goal of NOAA C-CAP within the coming decade(s), acquiring this data in the near-term and deriving the competitive advantage will require collaboration and funding through establishing partnerships.

The dramatically improved maps resulting from these pilot projects hold considerable promise to improve natural resource managers' ability to track wetland loss, gain, and land conversions (Figure X.49). Further, higher resolution mapping of land cover has appreciable potential to improve predictive models critical to allocating scarce conservation and restoration resources. For example, high-resolution mapping of impervious surfaces and other barriers to marsh transgression is imperative to the identification of priority marsh migration corridors (Enwright et al. 2016). During the CHPP Wetland Workshop, NOAA representatives indicated the possibility of including NC mapping at the one-meter resolution as a pilot project, however state matching funds would be required. The value of high-resolution land cover mapping extends well beyond coastal resource management applications, providing information invaluable to planning and administration of transportation, agriculture, utilities, and infrastructure, to name a few. As such, coastal resource management agencies should consider working with other state agencies to pull together the funding necessary to commission one-meter land cover mapping.

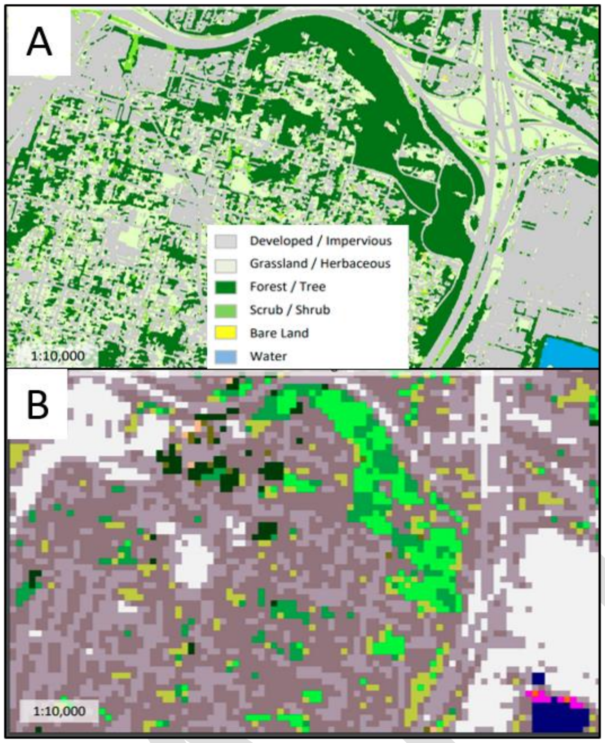

Figure X.49. Land cover map of Seattle Tacoma, WA with 1 m baseline draft mapping (A) and 30 m existing C-CAP mapping (B). Source: Rosa 2018, NOAA OCM.

There are several emerging technologies that have potential to allow more precise mapping with greater efficacy. Satellite data (Landsat) and aerial imagery (LIDAR) are more available but have low to moderate resolution. Unmanned Aircraft Systems (UAS) (ie drones), can provide rapid high resolution mapping but are not practical for a coastwide assessment (Ridge and Johnston 2020). A process known as data fusion, can use the high resolution UAS imagery, that has been field verified, to train classifications of lower resolution satellite imagery, such as WorldView (1.24 m resolution) or RapidEye (5.0 m resolution), improving accuracy of habitat classification with the satellite imagery, and is a method to generate 3D data Gray et al. in press; DEQ 2020). Another technique known as deep learning neural network uses a time series of satellite imagery to evaluate land cover change in a way that reduces post-processing time and increases speed of map creation. The Duke Marine Lab evaluated change in land cover in the Albemarle-Pamlico region between 1989 and 2011 with Landsat imagery and this deep learning technique. They were able to depict where farmland had transitioned to wetland; wetlands transitioning particularly along ditches and canals; and wetland forests along the estuarine shoreline converting to ghost forests (dead trees due to saltwater intrusion) (Gray et al. in press). Once proven, this technique would allow automated habitat classifications and change analysis rapidly. The ability to assess wetland change rapidly and accurately is critical to focusing management and restoration actions in priority areas in a time-effective manner.

North Carolina is also home to numerous universities and NGOs conducting research involving coastal wetland monitoring. However, the various sampling methodologies in these studies have impeded efforts to combine data to generate a meaningful picture of habitat condition at broader spatial or temporal scales. The development of standardized protocols to monitor wetlands, coupled with a central repository to submit reports or standardized data would facilitate policy managers and natural resource managers' ability to formulate actions based on robust, scientifically validated information. A repository of standardized wetland monitoring, which would include information from both published and unpublished studies, could minimize redundant sampling by researchers unaware of similar projects and facilitate synergistic collaborations. At the 2020 CHPP Wetland Workshop, most participants recognized the value of standard sampling protocol but thought that would be difficult due to different research objectives and funding sources. There was strong support for a central repository that included a database of who and where monitoring was occurring and completed reports. Both the formulation of some minimum standardized sampling protocol and the development of a centralized repository will require an inclusive process of consultation between practitioners, managers, and other user groups.

Expanded long-term funding opportunities also be explored. Wetland monitoring conducted by DWR has been funded primarily by the Environmental Protection Agency's (EPA) Wetland Program Development Grants (WPDG) that typically focus on short term monitoring projects. To provide a spatially robust inventory of the condition of the state's wetland resources over ecologically meaningful temporal scales, there is a need to move away from a dependence on external grant funding, which can be intermittent and variable in their research objectives, to a recurring state appropriation for standardized wetland monitoring that is critical to generating the data needed for science driven management.

Hard Bottom

Many aspects of the artificial and natural reef systems in NC have yet to be explored. A major concern with artificial reefs is if they are aggregating fishes from natural reefs where they are more easily overfished. Determining whether artificial reefs function only as refuge or if they support and increase fish populations is an important distinction that has not yet been addressed. There is also limited information on the biomass that can be supported by natural reefs and the comparison of artificial reefs. Currently, the artificial reefs in NC are being monitored by the Artificial Reef Program for material stability and major storm effects annually. However, there is no consistent monitoring of the condition of natural hard bottom within state waters. In addition to material and storm monitoring, and research to determine the function of artificial reefs, a monitoring program should be evaluated to inform the extent of natural hard bottom in NC state waters as well as the condition of both natural and artificial reefs.

Soft Bottom

Coastal soft bottom, sandy shoals and muds flats, are dynamic and ever shifting as other habitats expand or contract. These soft sediment environments are complex ecosystems containing strong physical gradients that affect the distribution of species and physicochemical conditions (Schenone and Thrush 2020). As coastal managers continue to mitigate environmental impacts with human needs, bathymetry data and the information that can be derived from it such as predictive models of tides, currents, temperature, and salinity, play a pivotal role in using and managing and understanding the status and trend of NC's coastal resources. Improved and updated bathymetry data of the sounds and NC's coastal waters will not only aid in the management of NC's soft bottom resource for activities such as aquaculture, but it will also contribute important information needed to determine the condition and support management decisions for almost all of the other coastal habitats as well.

In addition to updated information on the extent of soft bottom, it is also important to know the condition and quality of soft bottom habitat since it can affect species abundance and diversity of the benthic community. Monitoring of the sediments in soft bottom habitat for accumulated chemical and microbial contaminants, as well as the benthic organisms potentially impacted by these contaminants, is vital to understanding the status and trends of the soft bottom habitat. While some academic studies have been conducted and the NCCA does collect sediment quality data, the spatial and temporal scales are limited and there is no comprehensive coastwide estuarine soft bottom monitoring in NC. The

Bioassessment Branch of DWR has been conducting benthic macroinvertebrate assessments in the wadeable and non-wadeable lotic waters of NC since 1978. However, most sampling stations occur in the headwaters and very few occur in the tidal creeks. This program should be evaluated to expand existing sampling and parameters to fill this monitoring need.

1.6. Recommended Actions

1. By 2022, convene workgroups of DEQ agency staff, academics, and subject matter experts by coastal habitat type (i.e., water column, shell bottom, SAV, wetlands, hard bottom, and soft bottom) to define indicators metrics and identify data gaps and monitoring needs for the ability to determine long-term status and trends of coastal habitats and the estuarine ecosystem.
2. By 2023, develop a document (to be determined by the workgroups) to communicate to the public the ecosystem conditions of NC.

1.6.1. Water Column

1. By 2023, DWR will evaluate and prioritize the expansion of the statewide ambient monitoring system to fill known spatial data gaps in estuarine waters and to include the collection of water quality parameters defined by the water column metrics workgroup as indicators.
2. By 2022, DWR will develop a standardized procedure for algal bloom investigations for all involved agencies to collect appropriate metrics at the time of the event. This can be done by cross-training agency staff to perform investigations.

1.6.2. SAV

1. By 2023, DEQ to fund, develop, and implement a full-scale assessment program to conduct coastwide SAV mapping and monitoring at regular intervals (no more than 5 years apart).
2. By 2023, DWR will evaluate and prioritize the incorporation of shallow water sites (< 1m MLLW) that currently or historically contain(ed) SAV into the statewide ambient monitoring system.

1.6.3. Wetlands

1. By 2023, obtain state matching funds for NOAA C-CAP program to map NC's coastal plain at 1m resolution.
2. Continue to incorporate emerging technologies such a data fusion or deep learning neural networks, that rely on a combination of satellite imagery, drone imagery, and field verification into coastal wetland mapping and change analyses.
3. By 2022, DEQ agencies should form a multi-partner workgroup to collaborate on developing a coastal wetland mapping plan.
4. By 2022, DEQ agencies should form a multiagency workgroup should develop a set of minimum standardized sampling metrics for wetland monitoring projects to strengthen collaborative findings.
5. By 2023, DEQ should seek additional funding, preferably permanent funding, to expand coastal wetland monitoring conducted by DWR staff or other agencies as part of the NC DEQ Wetland Protection Plan.
6. By 2023, DEQ should create a central inter-agency repository of wetland mapping and monitoring projects and reports to improve efficacy of future monitoring.
7. By 2026, DEQ should determine status and trends of coastal wetland acreage, condition, and function based on the additional mapping and monitoring data obtained (DEQ WPP; DEQ CHPP 2020 Wetland Workshop).
8. By 2022, DEQ should enhance outreach on the value coastal wetlands for fisheries and ecosystem services, highlighting their importance for coastal resiliency.

1.6.4. Hard Bottom

1. By 2023, DMF will develop a monitoring strategy to determine how best to map natural reefs in NC state waters as well as monitor the condition of both natural and artificial reefs.

1.6.5. Soft Bottom

1. By 2023, DWR will examine the feasibility of expanding the benthic macroinvertebrate sampling to address spatial gaps in assessing the estuarine soft bottom benthic community condition.

1.1. Authority

1.1.1. NC Department of Environmental Quality

NC General Statues

143B-279.8. Coastal Habitat Protection Plans.

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